Communications Research Centre

LES 8/9 - 36/38 GHz GROUND TERMINAL

by

A.H. McEwen and J.L. Pearce

This work was performed for and under the sponsorship of the Department of National Defence, Chief of Research and Development branch with project management support from DCEM.

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COMMUNICATIONS RESEARCH CENTRE

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Table of Contents

		Page
List of Illustrations		v
List of Tables		vii
1.	INTRODUCTION	
1.1	Background	1
1.2	Initial Access	1
2.	LES 8 - LES 9 OVERVIEW	
2.1	Background	2
2.2	Initial Access	2
3.	INITIAL EQUIPMENT INSTALLATION	
3.1	Equipment Transportation	2
3.2	Equipment Shelter	2
3.3	Initial Results	2
4.	LINK BUDGET CALCULATIONS	
4.1	Background	6
4.2	Figure of Merit G/T_S Calculations	6
4.3	System Performance Calculation	8
4.4	System Selection	8
5.	EHF TERMINAL OVERVIEW	
5.1	Up/Down Converters	10
5.2	EHF Power Amplifiers	10
5.3	Transmit/Receive Signal Flow	10
5.4	Local Oscillator Generation	19
5.5	LES 8/LES 9 Translator	19
6.	RF SHELF DETAILS	
6.1	Background	22
6.2	IF Input Signal	22
6.3	Mixer Details	22
6.4	Local Oscillator Network	22
6.5	Tx Signal Selection	22
6.6	Tx Signal Amplification	27
6.7	Antenna and Feed System	27
6.8	EHF Receiver Section	27
6.9	Translation Circuits	27
7.	EHF TERMINAL SITE	
7.1	Construction Details	33
7.2	Radome Description	33
8.	CONTROL CONSOLE	
8.1	Equipment Configuration	33
8.2	Computer Equipment Rack	40
8.3	Monitor and Control Rack	40
8.4	Base Band Processing Rack	41
8.5	Signal Conversion Rack	41

Table of Contents (Concluded)

Page

9. POWER MONITOR AND SWITCH CONTROL
   9.1 Power Monitor System 42
   9.2 Switch Control Network 42

10. EXPERIMENTAL RESULTS
   10.1 SATCOM Experiments 42
   10.2 Satellite Link Attenuation 45
   10.3 Antenna Pointing Error Plots 45
   10.4 Antenna Pattern Results 48

11. EXPANSION OF SATCOM TERMINAL
   11.1 40/20 GHz Conversion 48
   11.2 Dual Feed Antenna System 48
   11.3 EHF Solid State HPA 53

12. CONCLUSION
   12.1 53

13. ACKNOWLEOGEMENTS 53

14. REFERENCES 53

Appendix A

Antenna Patterns 55

LIST OF ILLUSTRATIONS

		Page
Fig. 1	Loading equipment on Buffalo aircraft at Hanscome Air Force Base	3
Fig. 2	Naval terminal installed on portable antenna mount	4
Fig. 3	Naval terminal installation at C.R.C.	5
Fig. 4	Antenna Temp Graph vs Elevation Angle	7
Fig. 5	Error rates for several binary systems	9
Fig. 6	Series 3100 Pedestal	11
Fig. 7	Model 3843 Steptrack Controller, Front Panel	13
Fig. 8	Antenna Mounting Structure Scale Model	14
Fig. 9	Spacekom Mixers	15
Fig. 10	R.F. Shelf Layout	16
Fig. 11	R.F. Shelf Block Diagram	17
Fig. 12	R.F. Feed Assembly	18
Fig. 13	Local Oscillator Switch Diagram	20
Fig. 14	Local Oscillator Output	24
Fig. 15	Typical Bandpass Filter Plot	25
Fig. 16	Band Stop Filter Plot	26
Fig. 17	Hughes TWT Amplifier	29
Fig. 18	R.F. Feed Assembly	30
Fig. 19	Antenna T.R.G. 6' Dia.	31
Fig. 20	Site under construction	35
Fig. 21	Radome Installation at C.R.C.	36
Fig. 22	Radome Electromagnetic Performance Graph	38
Fig. 23	Control Console	39
Fig. 24	Power Monitor and Switch Control System	43

		Page
Fig. 25	Power Level Monitor and Keypad	44
Fig. 26	Signal Strength Recording	46
Fig. 27	Antenna Error Pointing Plot	48
Fig. 28	Antenna Azimuth Pattern - Beacon from LES 8 Dish	49
Fig. 29	Antenna Elevation Pattern - Beacon from LES 8 Dish	50
Fig. 30	Antenna Azimuth Pattern - Beacon from LES 8 Horn	51
Fig. 31	Antenna Elevation Pattern - Beacon from LES 8 Horn	52

LIST OF TABLES

TABLE		Page
1	Technical Characteristics Common to all Series 3100 Pedestals ...	12
2	LES 8 - LES 9 Frequency Plan	21
3	Test Data for Upconverter SpaceKom Model TF1 37(S) S/N 0L11	23
4	Data Sheet for Low-Noise TWT Amplifier	28
5	Test Data for Downconverter SpaceKom Model TF 37-P(S) S/N 0L12 ..	32
6	Translate Frequency Plan	34
7	Metal Space Frame Radome Salient Features	37
8	EHF Solid State HPA Specifications	54

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ABSTRACT

An E.H.F. SATCOM program was initiated by C.R.C. and D.N.D. in cooperation with Lincoln Laboratory M.I.T. using the satellites LES 8 and LES 9. The early phases of this program, including the design, development and installation of the E.H.F. SATCOM terminal at C.R.C. Ottawa Canada are discussed.

Experiments with the LES 8 satellite are described, the data recorded is presented and future plans for the satcom terminal are outlined.

1. INTRODUCTION

1.1 Background

In 1980, the military SATCOM group of the Communications Research Centre (CRC) was tasked by the Department of National Defence (DND) to study the military applications of satellite communications in the EHF spectrum. With the financial support of DND, a program which resulted in the installation of an EHF SATCOM terminal at CRC, Shirley Bay, Ottawa was established.

Two EHF satellites were already in orbit, the Lincoln series LES 8 and LES 9 operating in the (36-38) GHz frequency bands. After intensive discussions between Lincoln Labs, CRC and the U.S. Dept. of Defence a program was set up which allowed CRC limited access to both EHF satellites and the loan of some EHF equipment. Included in the loan was a small satellite communications terminal, called the Lincoln Laboratory Naval Terminal.

1.2 Initial Access

The initial access and first successful communications experiment over LES-8 was made on 10 March 1981 after installation of the U.S. Naval Terminal at CRC. The use of the terminal allowed CRC to conduct EHF SATCOM experiments while the permanent terminal was under construction.

Described in this paper are the design criteria, equipment selection, installation and testing of the permanent EHF SATCOM terminal. Satellite acquisition and tracking methods are discussed, and the initial experimental data recorded over the satellite link is summarized along with a discussion of future plans for the terminal.

2. LES 8/9 OVERVIEW

2.1 Background

The LES 8 and LES 9 satellites were placed in a synchronous, inclined orbit on March 14, 1976. The azimuth and elevation look angle variations from an Ottawa ground terminal location are 35° and 45° respectively. At EHF, the uplink and downlink signals require doppler frequency corrections of ±18 KHz for successful communications. The satellite payload is of a signal processing nature [1].

2.2 Initial Access

The initial access to be made on LES 8 was with the Lincoln Laboratory Naval Terminal. The antenna had a half power beam width of 1.3 degrees at the Tx frequency of 36 GHz. With such a relatively wide beam, it was decided that a very simple antenna mounting system and manual antenna steering would suffice for the first trials.

3. INITIAL EQUIPMENT INSTALLATION

3.1 Equipment Transportation

The loaned equipment from Lincoln Laboratory was transported to Hanscome Air Force Base for pick up by a Canadian Forces Buffalo Aircraft (Fig. 1). The terminal was flown to Uplands Air Force Base, Ottawa on 06 March 1981. Upon receipt of the equipment at CRC, the terminal was installed upon a modified portable antenna mount (Fig. 2). This was subsequently equipped with two stepping motors for AZ & EL tracking.

3.2 Equipment Shelter

The terminal was housed in a Poly Hut equipped with an RF window on one end. The hut was placed on the roof at CRC and aligned to the satellite azimuth look angle (Fig. 3).

Tracking of the satellite was accomplished from the EHF console by remotely energizing the stepping motors in the appropriate direction and using the received IF signal strength as monitored on a spectrum analyzer to optimize the pointing angle.

3.3 Initial Results

Measurements made with the Naval Terminal and a CW beacon from LES 8 showed a C/N_0 of 60 dB Hz. This agrees favourably with the calculated values as shown below:

LES 8 dish EIRP	=	38.8 dBw
Radome Transmission Loss	=	.78 dB
Earth Illumination Level	=	-125.5 dBw/m^2
System Temperature	=	2250° K
Naval Terminal Antenna Gain	=	42.5 dBi
Figure of Merit	=	9 dB/K
C/N_0	=	59.5 dB/Hz

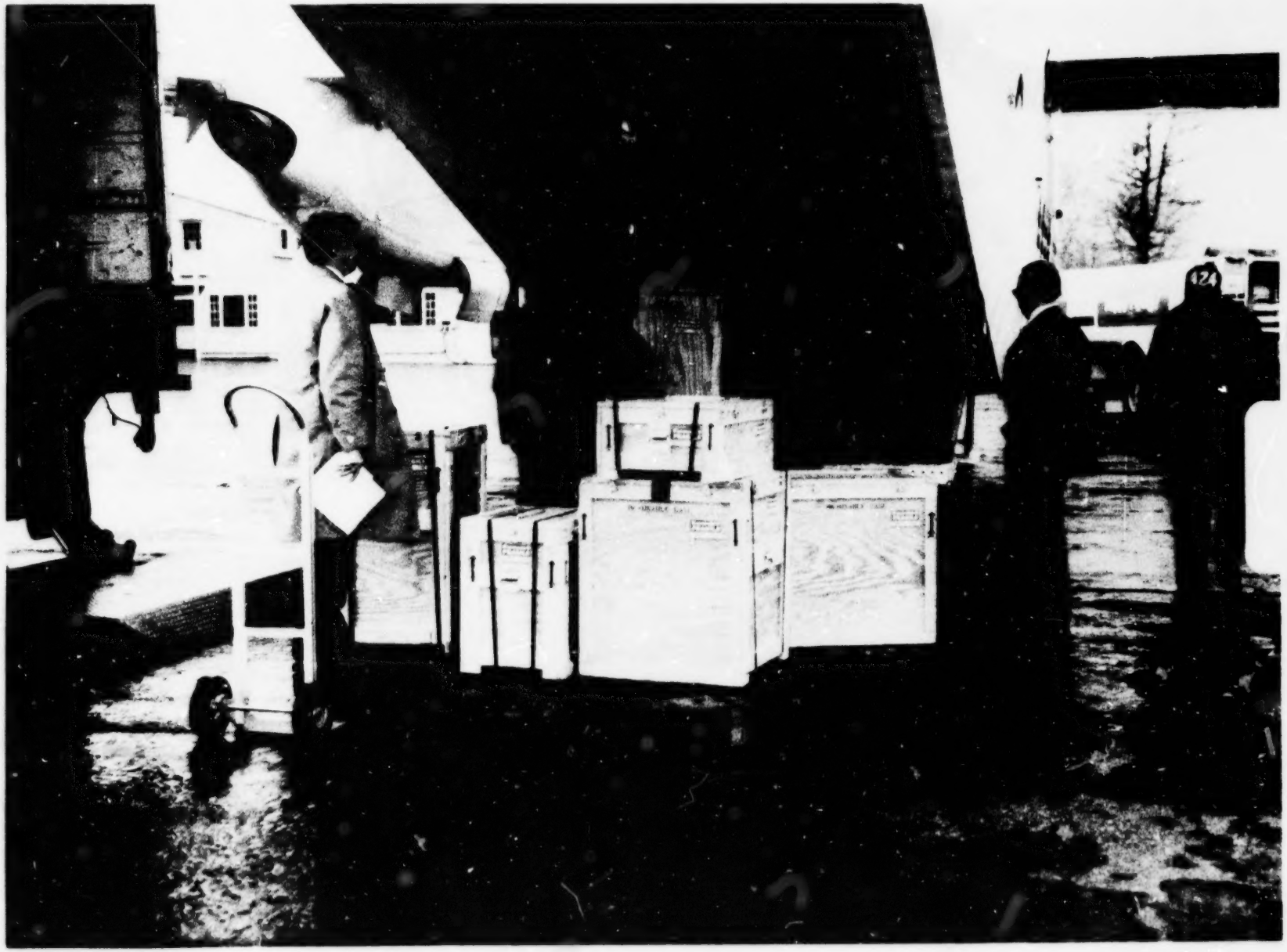


Fig. 1 Loading equipment on Buffalo aircraft at Hanscom Air Force Base

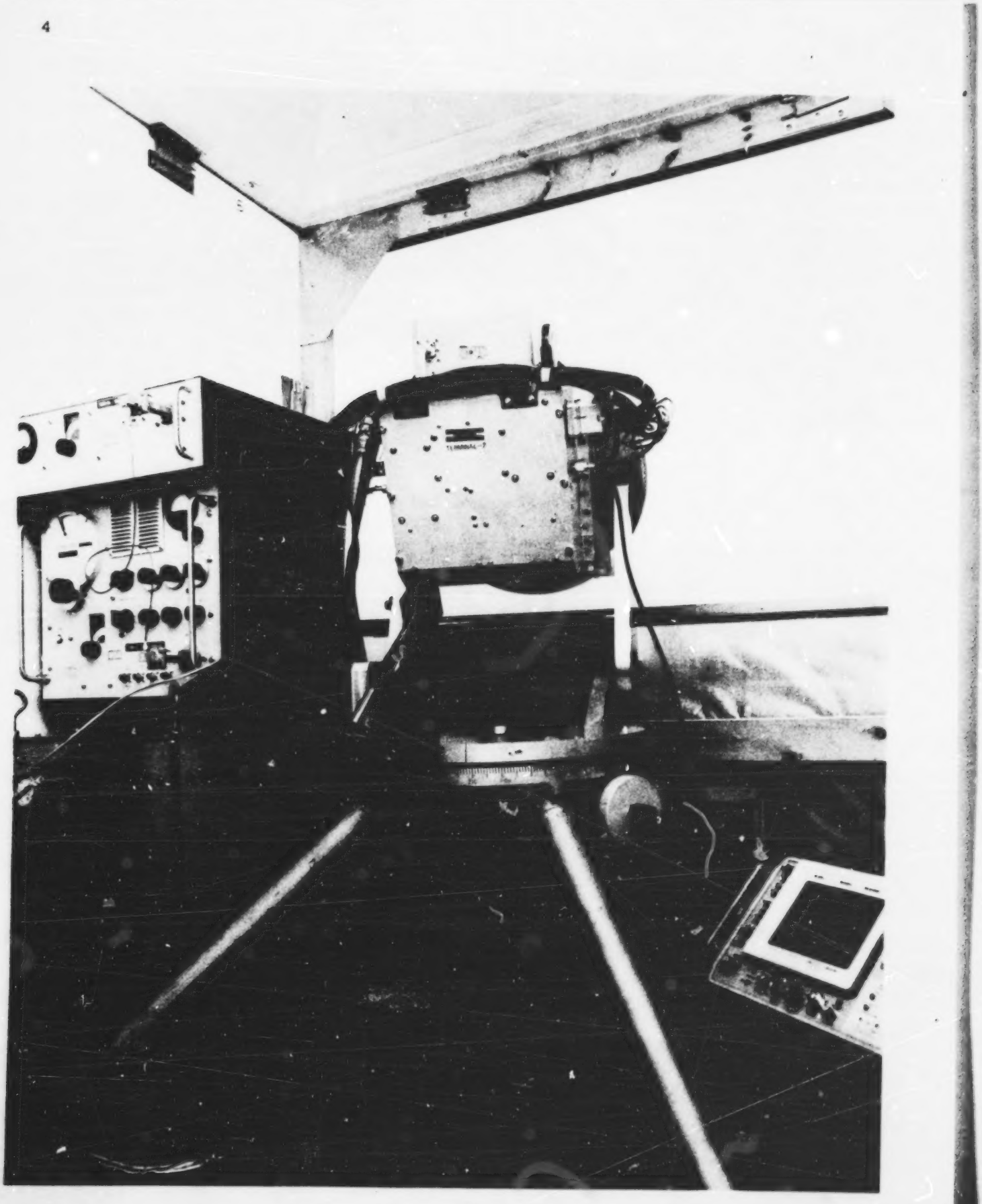


Fig. 2. Naval terminal installed on portable antenna mount

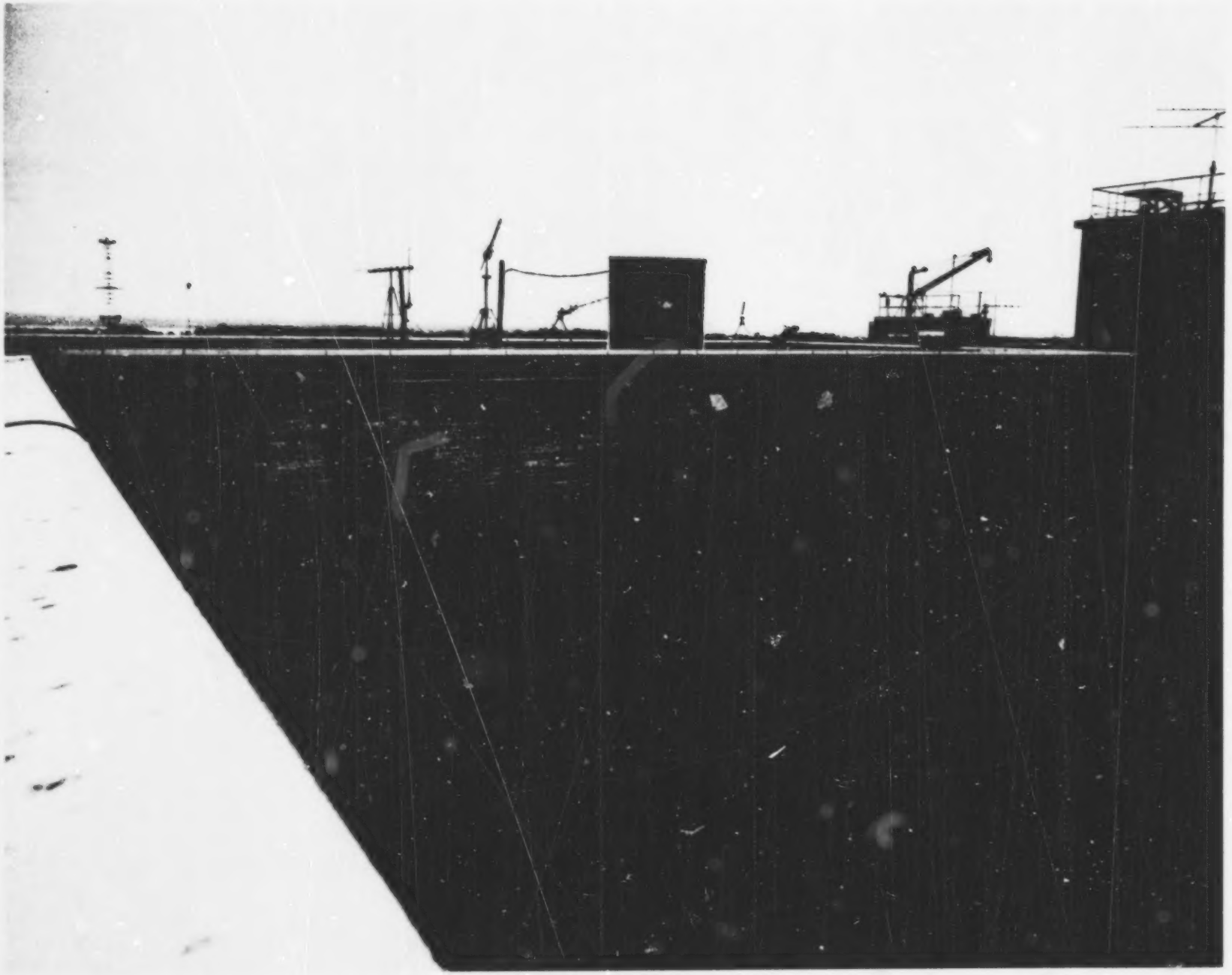


Fig. 3 Naval terminal installation at C.R.C.

4. LINK BUDGET CALCULATIONS

4.1 Background

Two downlink budget calculations are shown which represent the two system configurations considered for the permanent ground terminal installation. System 1 would incorporate a 4 foot diameter antenna and a low noise amplifier, while system 2 would use a 6 foot diameter antenna and the best low noise mixer obtainable. Both systems would have the same loss between the antenna terminals and the L.N.A. as shown below:

Polarizer and orthomode coupler loss	.2 dB
Wave guide switch loss	.3 dB
Band pass filter 38 GHz	.4 dB
Band stop filter 36 GHz	.4 dB
Wave guide path loss	.1 dB
TOTAL INSERTION LOSS (Lr)	1.4 dB

4.2 Figure of Merit G/T_s Calculations

The G/T_s of the receiver system can be determined from the antenna gain and from the system temperature (T_s) referred to the antenna, given in the following formula [2].

$$T_s = T_a + ((1-L)/L)T_0 + (1/L)T_r$$

where T_a is the antenna noise temperature in degrees K
T_r is the receiver noise temperature referred to the LNA or Low Noise Mixer in degrees K
T_0 is the temperature of the loss elements
L is the loss (as a decimal fraction) between the antenna terminals and the LNA.

$$L = 10^{(-0.1Lr)}$$

L_r is the loss in dB between the antenna terminals and the LNA. For both systems Lr = 1.4 dB, (shown above) L = .72, T_a = 140°K (Fig. 4) [3], and T_0 = 290°K.

A 3.5 dB (360°K) value for T_r is used in system 1 calculations, while 8.4 dB (1700°K) is used in system 2. Substituting these values in the equation yields the following results:

System 1

$$T_s = 140 + ((1 - .55)/.55)290+(1/.55)360$$
$$T_s = 1031°K$$

G_a for a 4' diameter dish at 38 GHz and 55% efficiency = 51 dB

Therefore: G_a/T_s = 22.25 dB/K

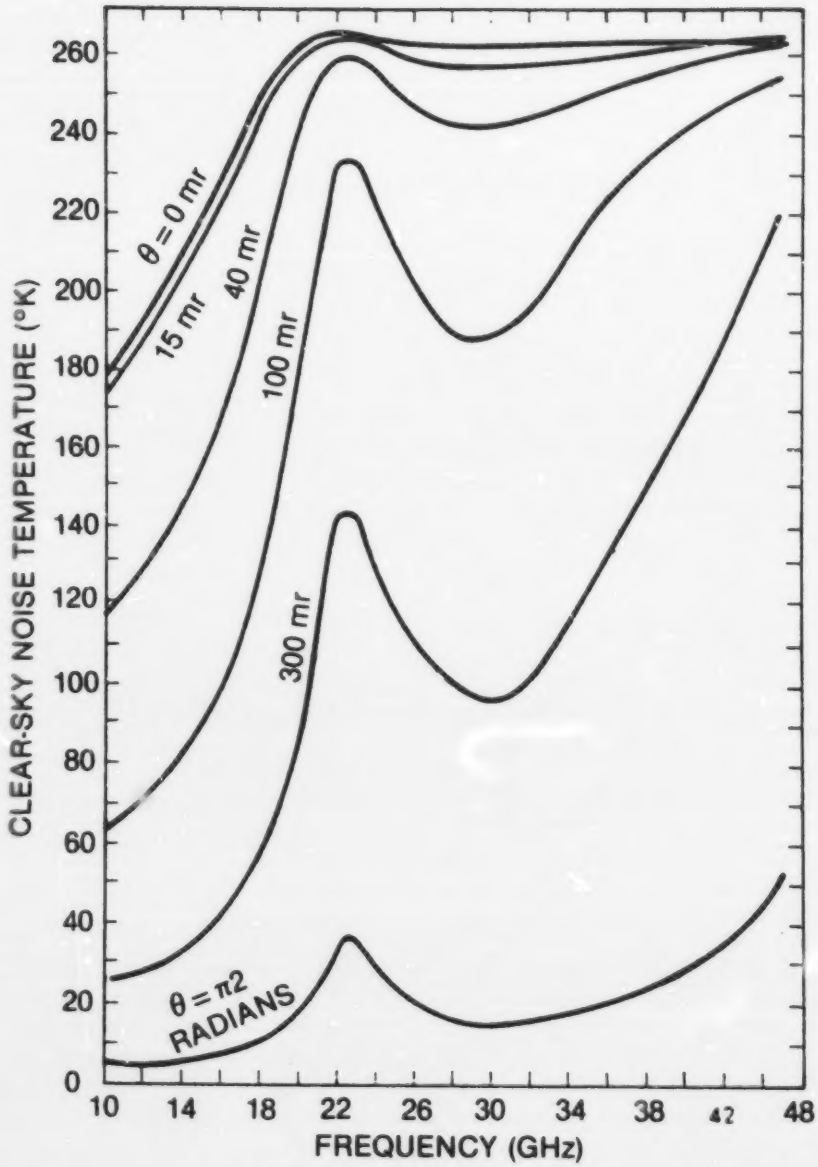


Fig. 4 Antenna Temp Graph vs Elevation Angle*

* Ref. [3]

System 2

$T_S = 140 + ((1-.72)/.72)290 + (1/.72)1700$
$T_S = 2614°$ K

G_a for a 6' diameter dish at 38 GHz and 55% efficiency = 54.5 dB

Therefore $G_a/T_S = 20.2$ dB/K

4.3 System Performance Calculation

System 1

G_a 4' Dia = 51 dB
Beamwidth 3 dB = .46°
LES 8 EIRP (Dish) = 38.8 dBw
Transmission Loss = 1.2 dB
Illumination level = -126 dBw/m^2
Figure of merit (G_a/T_S) = 22.5 dB/K
C/N_0 = 72 dB-Hz

System 2

G_a 6' Dia = 54.5 dB
Beamwidth 3 dB = .31°
LES 8 EIRP (Dish) = 38.8 dBw
Transmission Loss = 1.2 dB
Illumination Level = -126 dBw/m^2
Figure of merit (G_a/T_S) = 19.5 dB/K
C/N_0 = 70 dB-Hz

The data rate to be used over the satellite link is 10 KB/s with a Differentially Encoded PSK (DECPSK) modulation. We are interested in achieving bit error rates 1 X 10^{-5}. To meet this requirement we need a theoretical C/N_0 of 50 dB-Hz (Fig. 5) [4].

Since both systems configurations yield a theoretical link margin of 20 dB, the choice of systems then became one of budgetary restraints and antenna tracking problems ie: antenna 3 dB beamwidths.

4.4 System Selection

System 1 was eliminated due to the cost of a suitable LNA. The next problem to be considered was one of satellite acquisition and tracking due to the narrow antenna beamwidth, 0.3 degrees at half power point. The maximum static pointing angle that could be tolerated was estimated as 0.1 degrees while the smallest increment command that the chosen pedestal would execute was 0.01 degrees.

Antenna pedestals exist that will give an order of magnitude better accuracy but as before budget restraints forced an acceptance of an 0.01 degree command precision level. The antenna pedestal chosen was a Scientific Atlanta Model 3100 (Fig. 6 and Table 1) along with a model 3843 Steptrack Controller (Fig. 7). When such items as the backlash of the gears

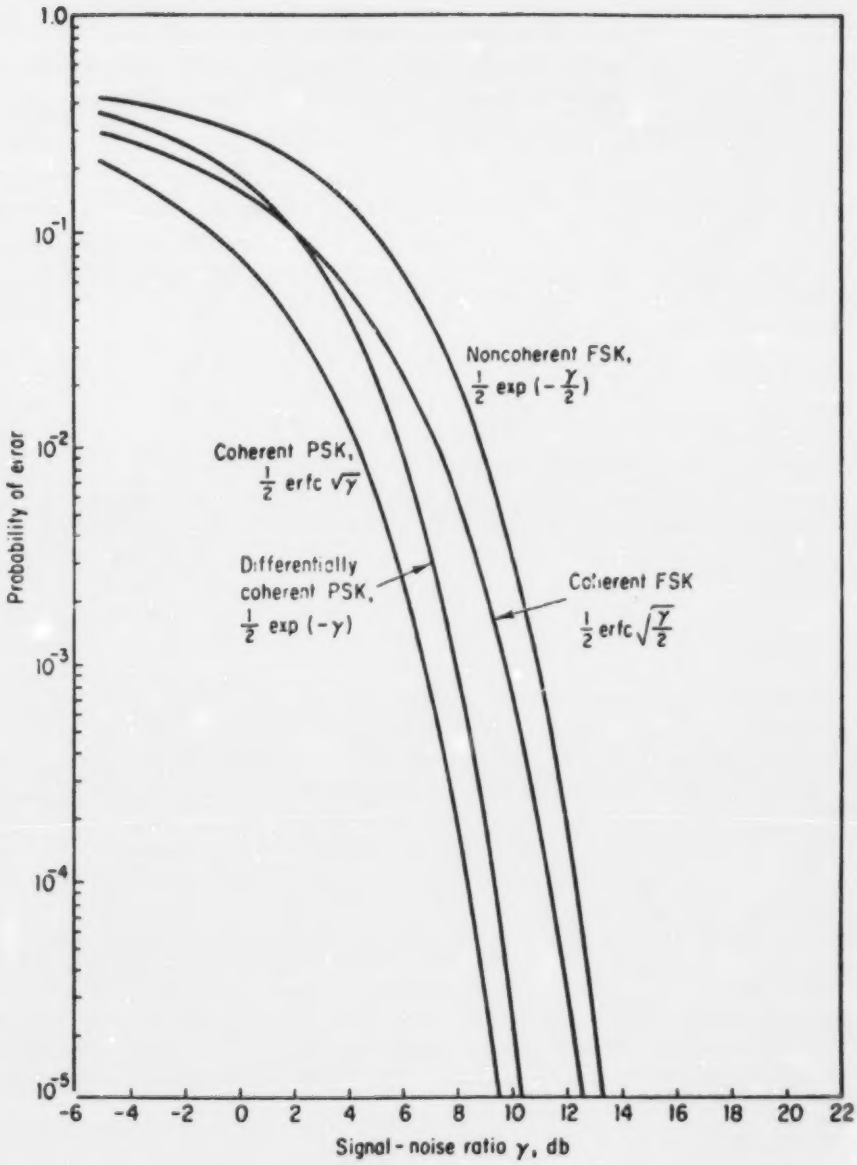


Fig. 5 Error rates for several binary systems*

* Ref. [4]

are considered, it is estimated that the pointing precision is of the order of 0.05 degrees.

5. EHF TERMINAL OVERVIEW

The selection of the antenna pedestal allowed the mechanical configuration of the mounting shelf for component layout to be established. A scale model of the complete antenna mount is shown in Fig. 8.

5.1 Up/Down Converters

A Honeywell Spacekom mixer-tripler (Fig. 9) combination was chosen for up/down signal conversion. The use of a mixer tripler device allowed the use of local oscillators in the 12 GHz region thus lowering the cost of signal conversion components. Waveguide switching of local oscillators and filters was incorporated to allow coverage of both LES 8 and LES 9 satellites.

5.2 EHF Power Amplifiers

Transmit power is supplied by a Hughes 2 watt Ka band amplifier driven by a Watkins Johnson TWT preamplifier. Provision to translate and test the system is also included. The RF shelf physical layout is shown in Fig. 10. A 6 watt TRW solid state power amplifier is also available for use with LES-8.

5.3 Transmit and Receive Signal Flow

A block diagram of the RF system is shown in Fig. 11. The 70 MHz input signal shown on the left, is a DECPSK modulated intermediate frequency signal which is first pre-corrected for uplink doppler shift by a computer controlled phase-coherent Dana synthesizer, which mixes the signal up to a 115 MHz IF. This signal is then upconverted to 900 MHz by an AIL synthesizer which can frequency hop the uplink signal under computer control if required.

The 900 MHz signal is filtered, amplified and applied to the upconverter to generate a 36 GHz or 38 GHz transmit signal depending on the selected local oscillator. The Tx signal is then routed through the appropriate bandpass filters by wave guide switches and fed to a low noise TWT preamplifier. The amplified signal is isolated and level set to match the input requirements for the 2 watt Hughes HPA. Monitor points are provided at the input and output of the HPA.

The signal is then switched through the appropriate bandpass filters by wave guide switches and applied to the antenna through a 4 port waveguide switch, orthomode transducer and circular polarizer. This combination allows transmissions of right hand circular polarized signals (RHCP) and reception of left hand circular polarized signals (LHCP) or the inverse of this combination depending on the switched signal routing to the orthomode coupler ports. The antenna feed assembly consisting of the orthomode transducer and polarizer is shown in Fig. 12. The side arm of the orthomode transducer is the RHCP port and the through arm is the LHCP port.

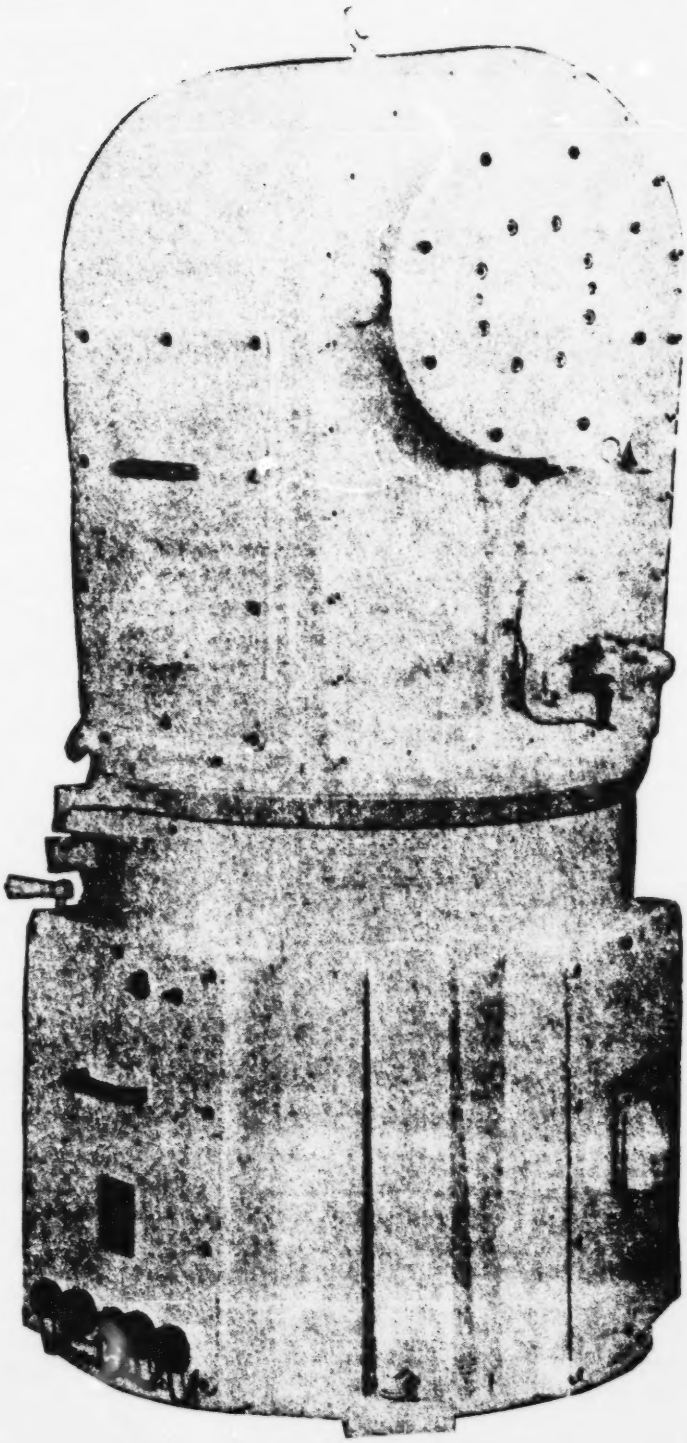


Fig. 6 Series 3100 Pedestal

TABLE 1

TECHNICAL CHARACTERISTICS COMMON TO ALL
SERIES 3100 PEDESTALS

Characteristic	Specification
Withstand Torque	2000 lbf-ft
Input Power Required	208/120V, 50/60 Hz, 3ϕ, 4 wire
Drive Type	DC Servomotor, 1 hp
Compliance	1 X 10^{-6} Rad/ft-lb
Azimuth Bearing Dia	23 in
Azimuth Beraring Overturning Moment	30,000 ft-lbf
Elevation Bearing Dia (two)	9 in
Max External Dead Weight Load	3,000 lb
Orthogonality Tolerance	0.02°
Data Take-off Packages (Both Axes)	Size 23, 120V, 60-Hz synchro transmitters and control transformers
Electromechanical Brake Holding Torque	1000 ft-lbf
Pedestal System Accuracy (Typical)*	Static error, 1:1 speed 0.1° peak; 1:1 and 36:1 speed, 0.05°; velocity error, 0.003°/°/s
Power Gearing Backlash	0.05°
Torque Sensitivity	10,000 ft-lbf/°
Pedestal Weight	800 lb

* Values are cumulative. Typical errors are listed. Values will vary depending on specific load conditions.

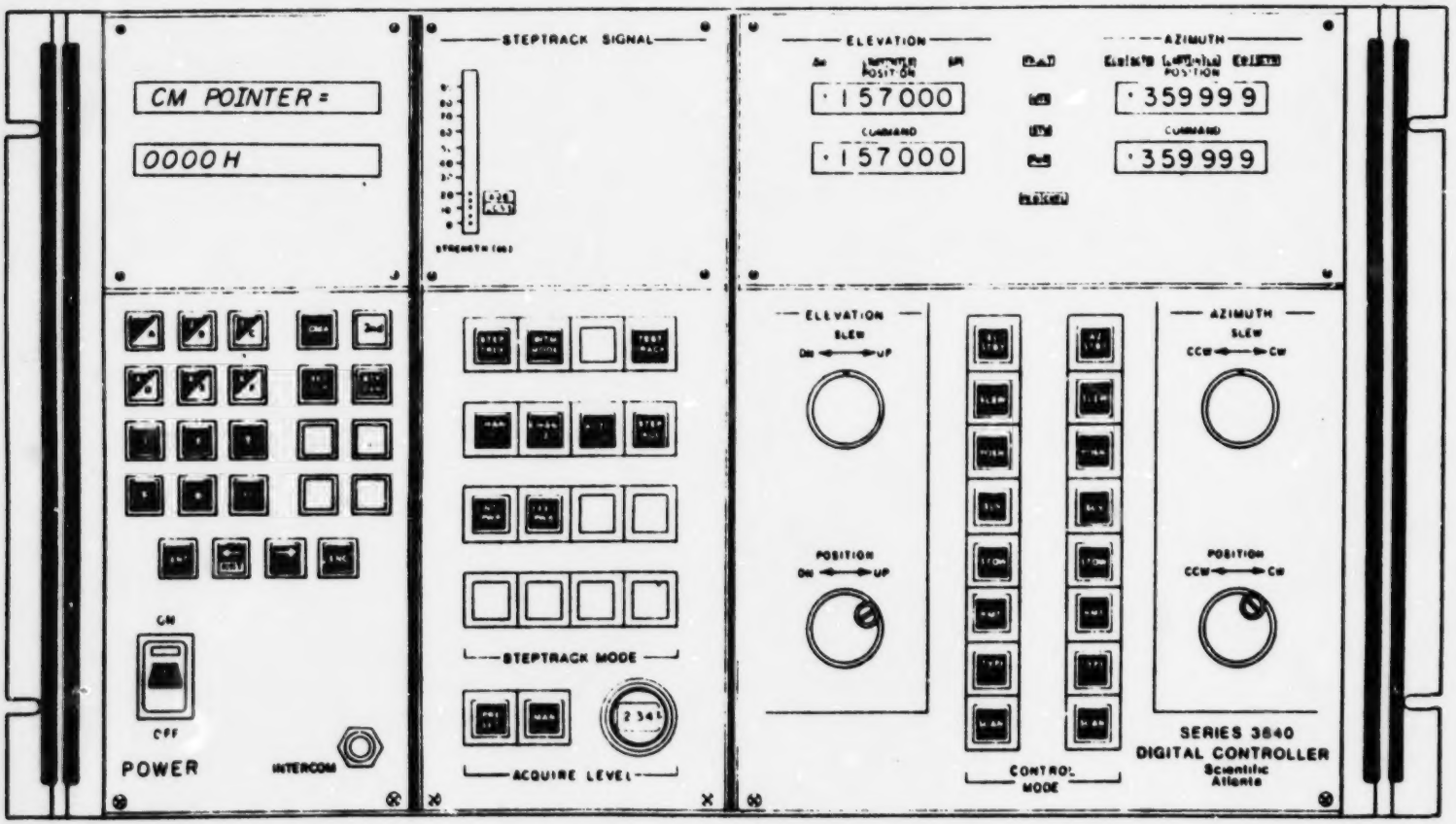


Fig. 7 Model 3843 Steptrack Controller, Front Panel

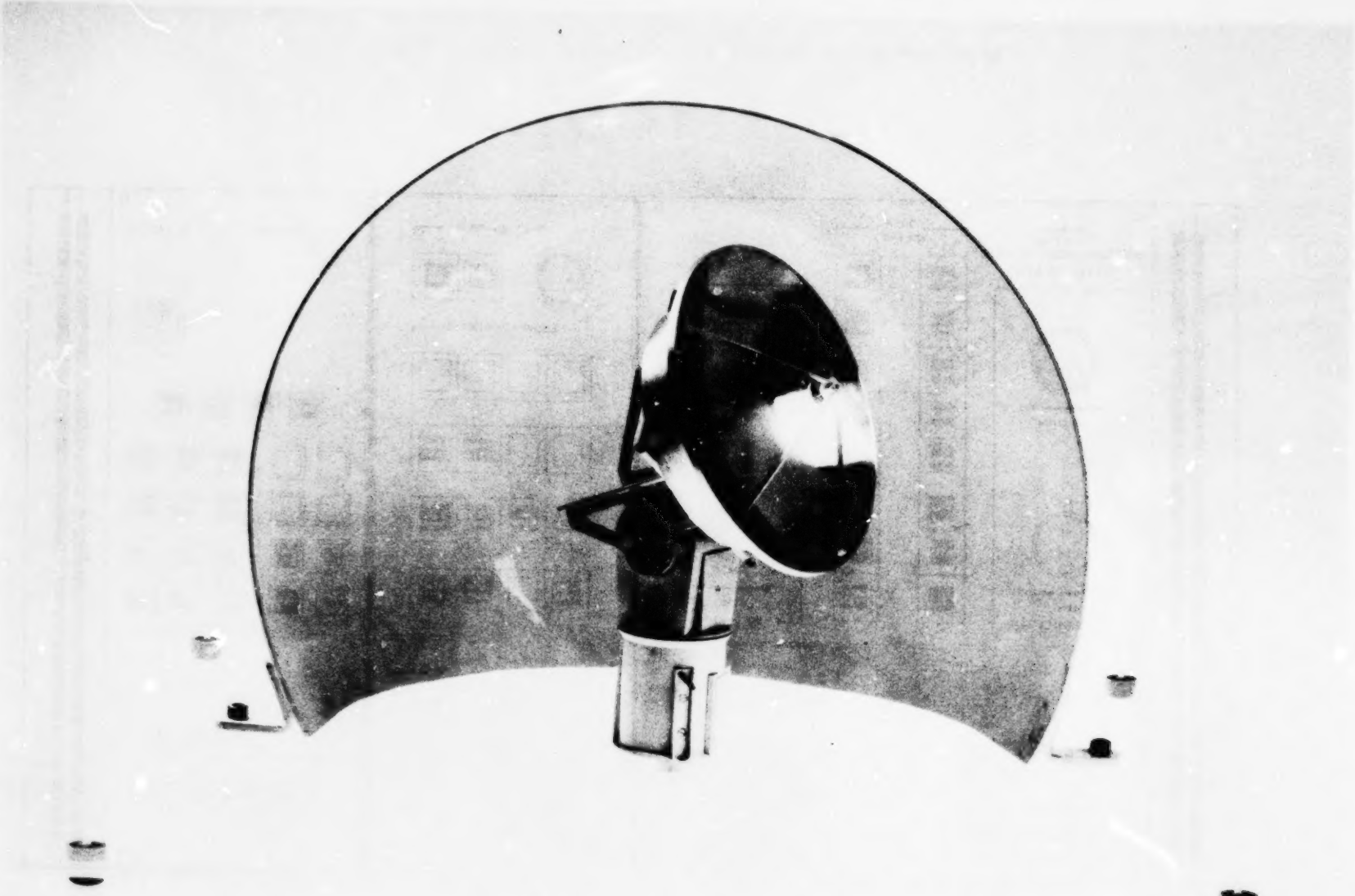


Fig. 8 Antenna Mounting Structure Scale Model

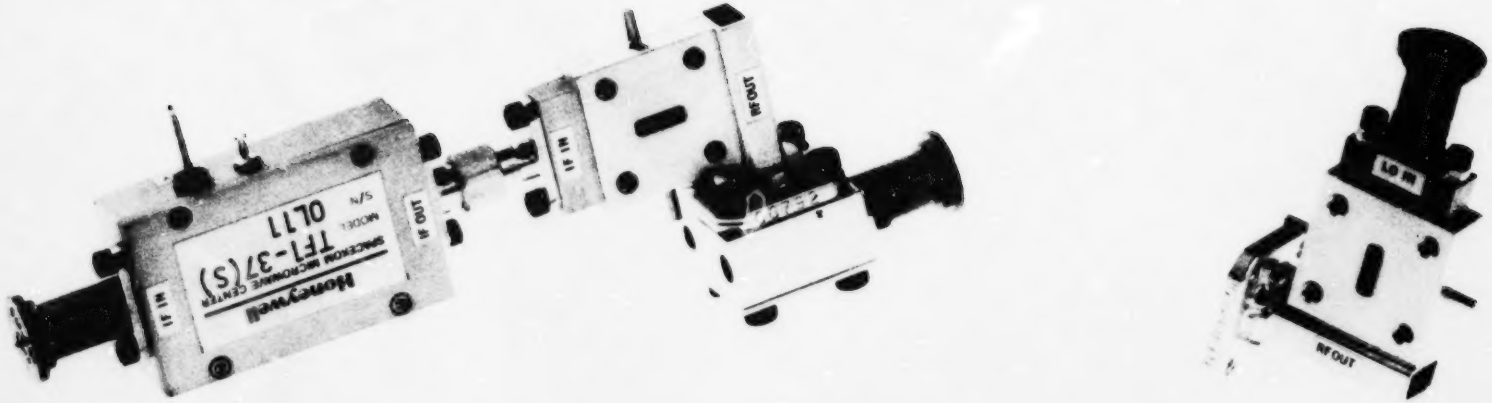


Fig. 9 Spacekom Mixers

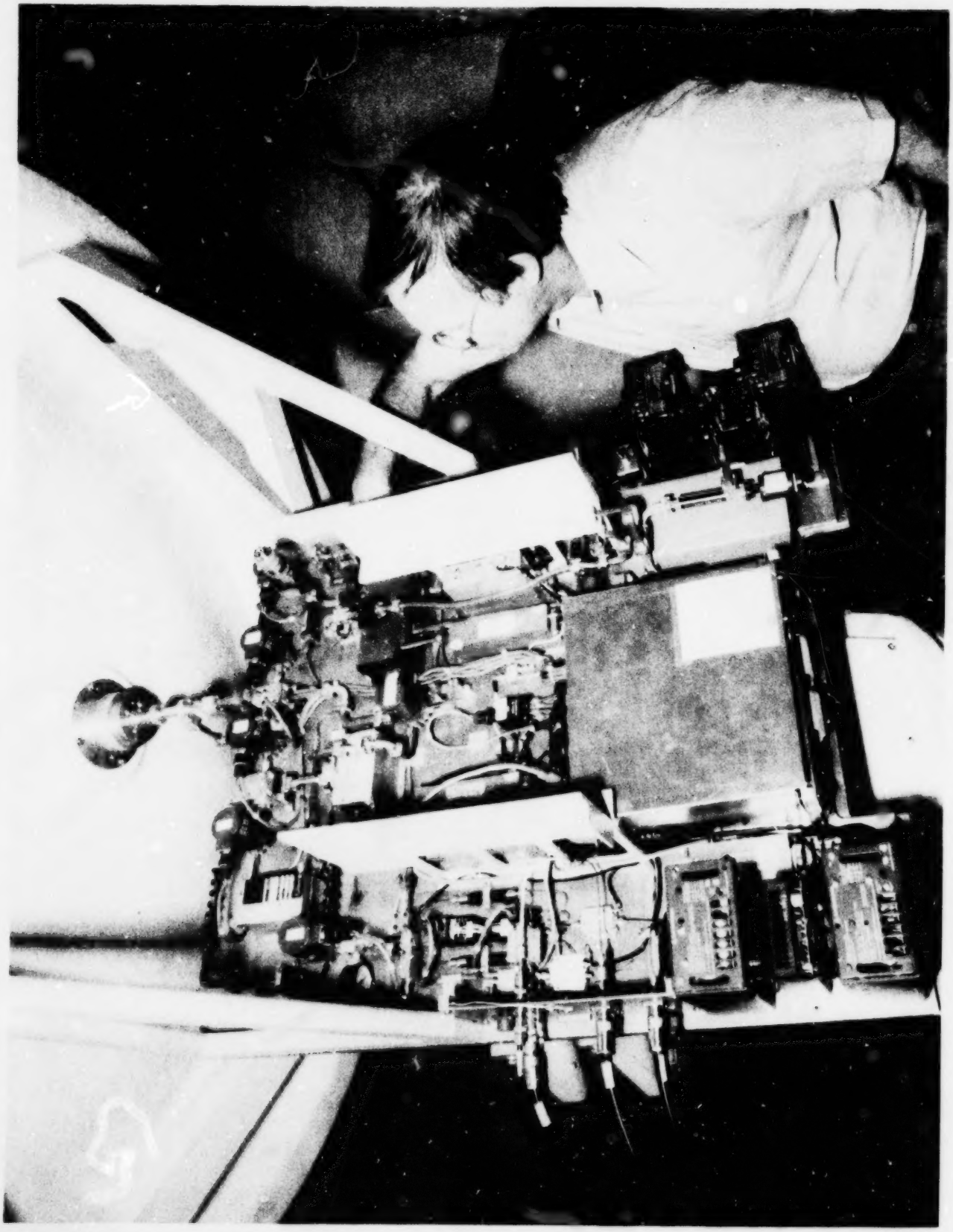


Fig. 10 R.F. Shelf Layout

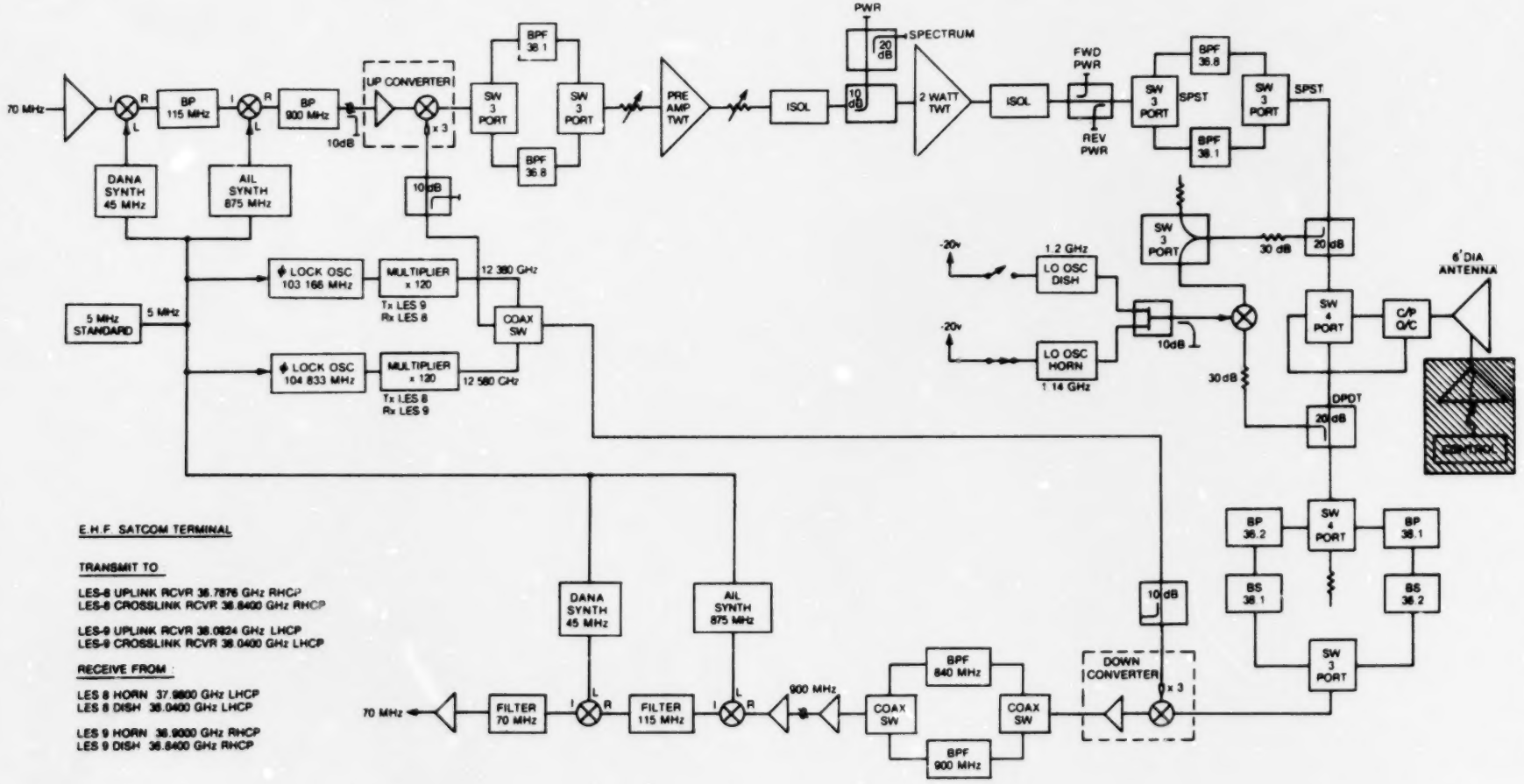


Fig. 11 R.F. Shelf Block Diagram

Fig. 12 R.F. Feed Assembly

The received signal from the antenna/feed assembly is switched through the band pass/band stop filter pair for the selected satellite by two wave guide switches, one of which allows for injection of a calibration signal (terminated when not in use).

The downlink signal is then fed to a low noise mixer and down converted to a 900 or 840 MHz IF signal. Coaxial switches route the IF signal through the appropriate bandpass filter to be amplified and applied to the first IF mixer. The 900 MHz or 840 MHz signal is down converted, filtered and applied as a 115 MHz signal to the second IF mixer. Here the local oscillator generated by a second Dana synthesizer under computer control applies a doppler frequency correction factor to the downlink signal. The resultant 70 MHz signal is filtered, amplified and fed to the DEQPSK demodulator.

This completes the description of the up and down link signal paths. Two remaining circuits of interest are the local oscillator signal generation and the translation loop.

5.4 Local Oscillator Generation

The LES 8/9 SATCOM terminal is a phase coherent system which requires all synthesizers and local oscillators to be phase locked to an external (5-10) MHz reference signal. This signal is generated by a rubidium standard [Tracor Model 3040], buffered and distributed to the all local oscillator elements.

The EHF local oscillators are generated by phase locking two basic crystal oscillators at 103.166 MHz and 104.833 MHz to the 5 MHz ref signal. The outputs of these two oscillators are multiplied by 120 to generate 12.380 GHz and 12.580 GHz.

These two frequencies are used in conjunction with a 4 port coaxial switch as local oscillators for the EHF up converter and down converter pair (Fig. 13).

These frequency converters are double side band mixers making use of a tripler diode integral to the local oscillator port. The use of the upper and lower mixer side bands plus the interchange of the 12.380 GHz and 12.580 GHz signals through the 4 port switch allow generation of all frequencies required to access the LES 8 and LES 9 satellites, in all operational modes. The satellite frequency plan as well as the required ground terminal oscillator and IF frequencies are shown in Table 2.

5.5 LES 8/LES 9 Translator

Provision for testing the system when satellite time is not available is provided by two Frequency West oscillators which provide the translation frequencies for LES 8. Two translate frequencies are provided to test the LES 8 dish/horn configuration.

The Tx power is sampled, attenuated and fed to the RF port of the translate mixer (Fig. 11). A coaxial switch selects one of two oscillators to supply the correct translate frequency. The IF output is attenuated to

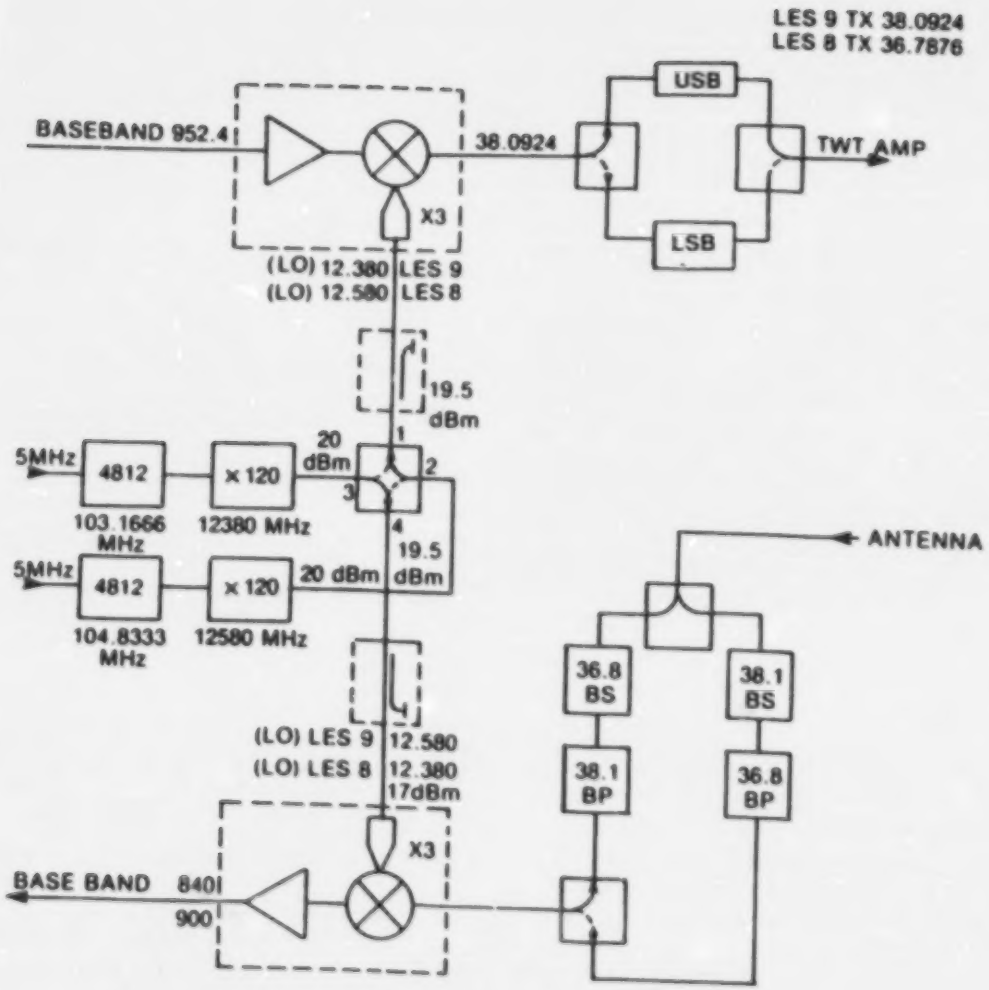


Fig. 13 Local Oscillator Switch Diagram

TABLE 2

LES 8 - LES 9 FREQUENCY PLAN

EHF LOCAL OSCILLATOR FREQUENCY GENERATION

Ø LOCKED OSC MHz	120X MULTIPLIER GHz	X3 TRIPLER GHz
103.1666666	12.380	37.140
104.8333333	12.580	37.740

EHF SATCOM FREQUENCY ALLOCATION

IF MHz	LOCAL OSC GHz	TRANSMIT GHz	RECEIVE GHz	SATELLITE
900	37.740	36.840	-	LES 8
900	37.140	-	38.040	LES 8
840	37.140	-	37.980 (HORN)	LES 8
900	37.140	38.040	-	LES 9
900	37.740	-	36.840	LES 9
840	37.740	-	36.900 (HORN)	LES 9

approximate the level of the received satellite signal and injected into the receiver arm via a waveguide switch and directional coupler. This waveguide switch terminates the translate mixer IF port into a 50 load when accessing the satellite thus isolating the translate path by an additional 50 dB.

6. RF SHELF DETAILS

6.1 Background

The details of the RF shelf are described following the transmit and receive signal paths illustrated in Fig. 11. Indicated are the signal levels at the monitor test points, the microwave devices used as well as the data obtained on device performance. Refer to Fig. 11 and Fig. 13 again for the system block diagrams.

6.2 IF Input Signal

The input signal to the RF shelf is a PSK modulated 900 MHz signal at a power of -26 dBm. This signal is level set, amplified and applied to input of the upconverter preamplifier through a 10 dB directional coupler. This coupler provides a signal level monitor point.

6.3 Mixer Details

The upconverter used is a Honeywell Spacekom model TF1-37(S). This is a double side band mixer with an integral frequency tripler in the local oscillator port. The tripler allows the use of a 12.580 GHz/12.380 GHz local oscillator at a drive level of +17 dBm, to generate the final local oscillator frequencies of 37.740/37.140 GHz. Test data for the model TFI-37(s) is shown in Table 3, and the upconverter itself shown in Fig. 9. The upconverter preamp has a nominal gain of 43 dB with a 1 dB compression point at $\geq$ -30 dBm input.

6.4 Local Oscillator Network

The local oscillator networks consists of two Zeta Laboratories model 4812 VXCO's phase locked to a 5 MHz rubidium standard. The 4812 oscillator outputs are multiplied 120 times by ZETA Lab model MI-12 active frequency multipliers. The multiplier outputs are switched (Fig. 13) to the up/down converters. A typical multiplier output is shown in Fig 14.

6.5 Tx Signal Selection

The 900 MHz IF signal is upconverted in the model TF1-37 Spacekom mixer, then the upper or lower side band signals are selected through 3 port wave guide switches and bandpass filtering to achieve the transmit frequencies for the LES 8 or LES 9 satellites.

The waveguide switches are MDL model 38SR26, providing $\geq$ 50 dB isolation for the selected signal path. The bandpass filters are Gamma-F Corporation WR28 waveguide filters. A typical bandpass filter plot is shown in Fig 15 and a band stop filter plot in Fig 16.

TABLE 3

Test Data for Upconverter SpaceKom Model TF1 37(S) S/N 0L11

L.O. Input Freq (GHz)	R.F. Output Freq (MHz)	Conv. Loss DSB (dB)	LO Power dBm	LO RF Isolation (dB)	RF IF Gain (dB)	RF input MHz A - 10 dBm thru D.C. Block
12.380	36.240 38.040	3.0	+17.0	$\geq$ 25.0		900
↓	36.190 38.090	3.0	↓			950
↓	36.140 38.140	3.1	↓			1000
↓	36.090 38.190	2.8	↓			1050
12.580	36.840 38.640	3.3	+17.0	$\geq$ 25.0		900
↓	36.790 38.690	3.2	↓			950
↓	36.740 38.740	3.3	↓			1000
↓	36.690 38.790	3.4	↓			1050

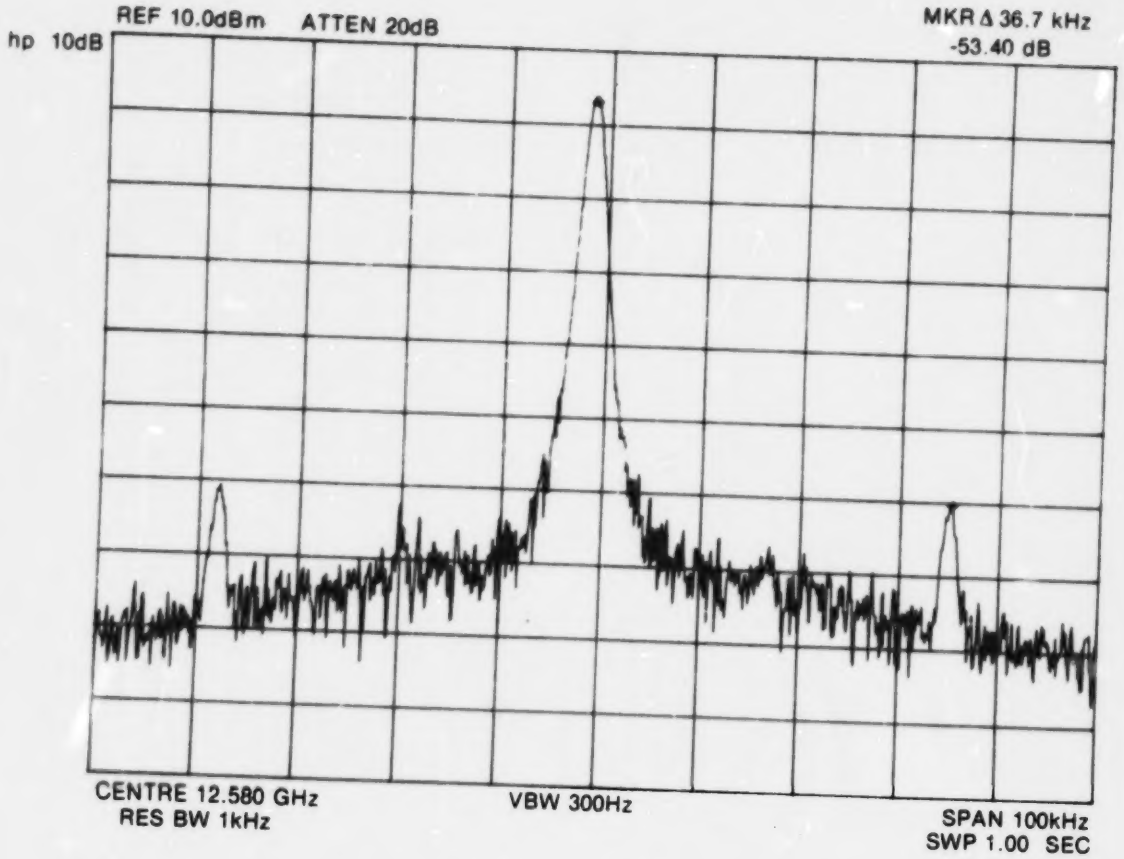


Fig. 14 Local Oscillator Output

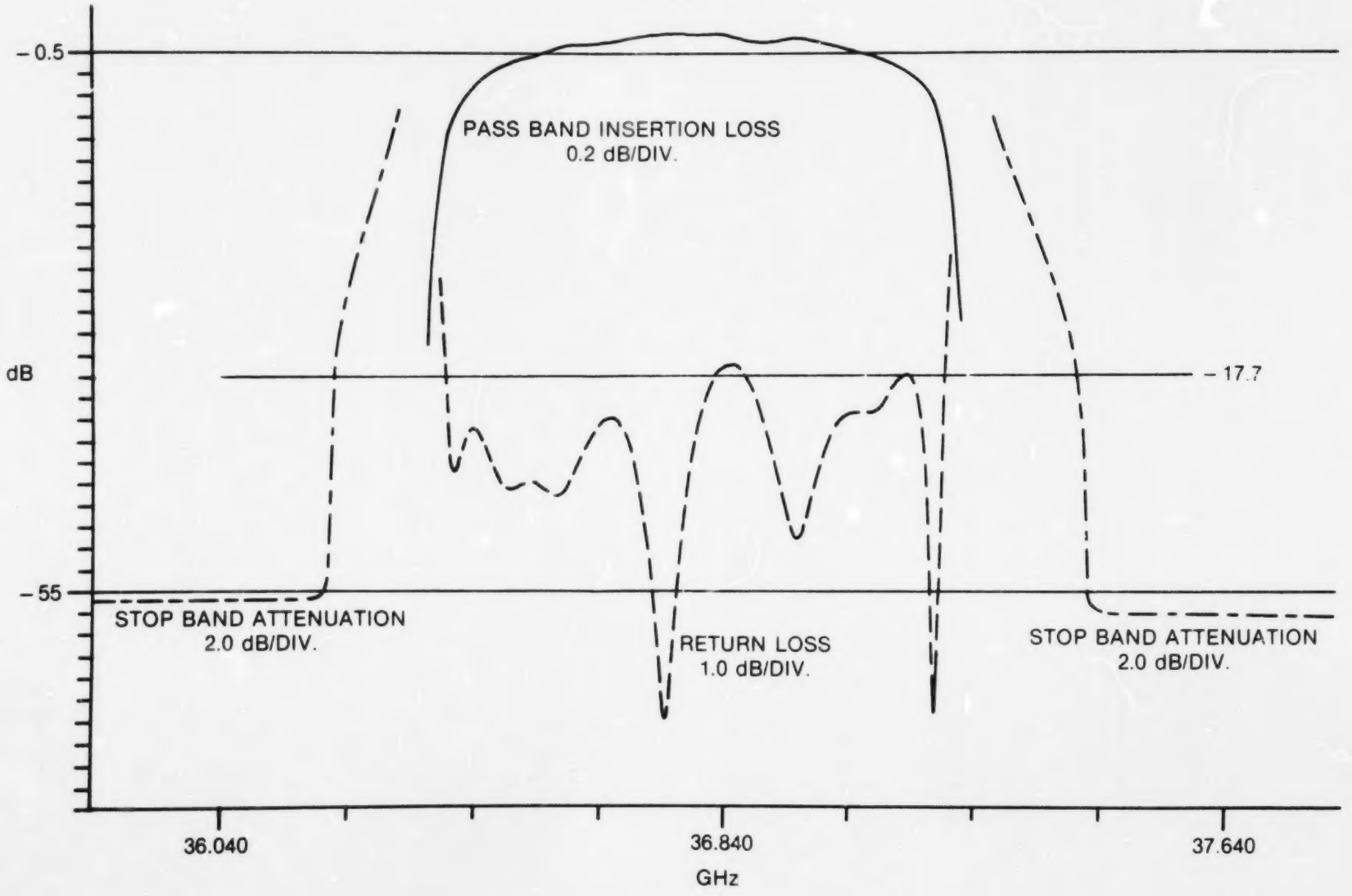


Fig. 15 Typical Bandpass Filter Plot

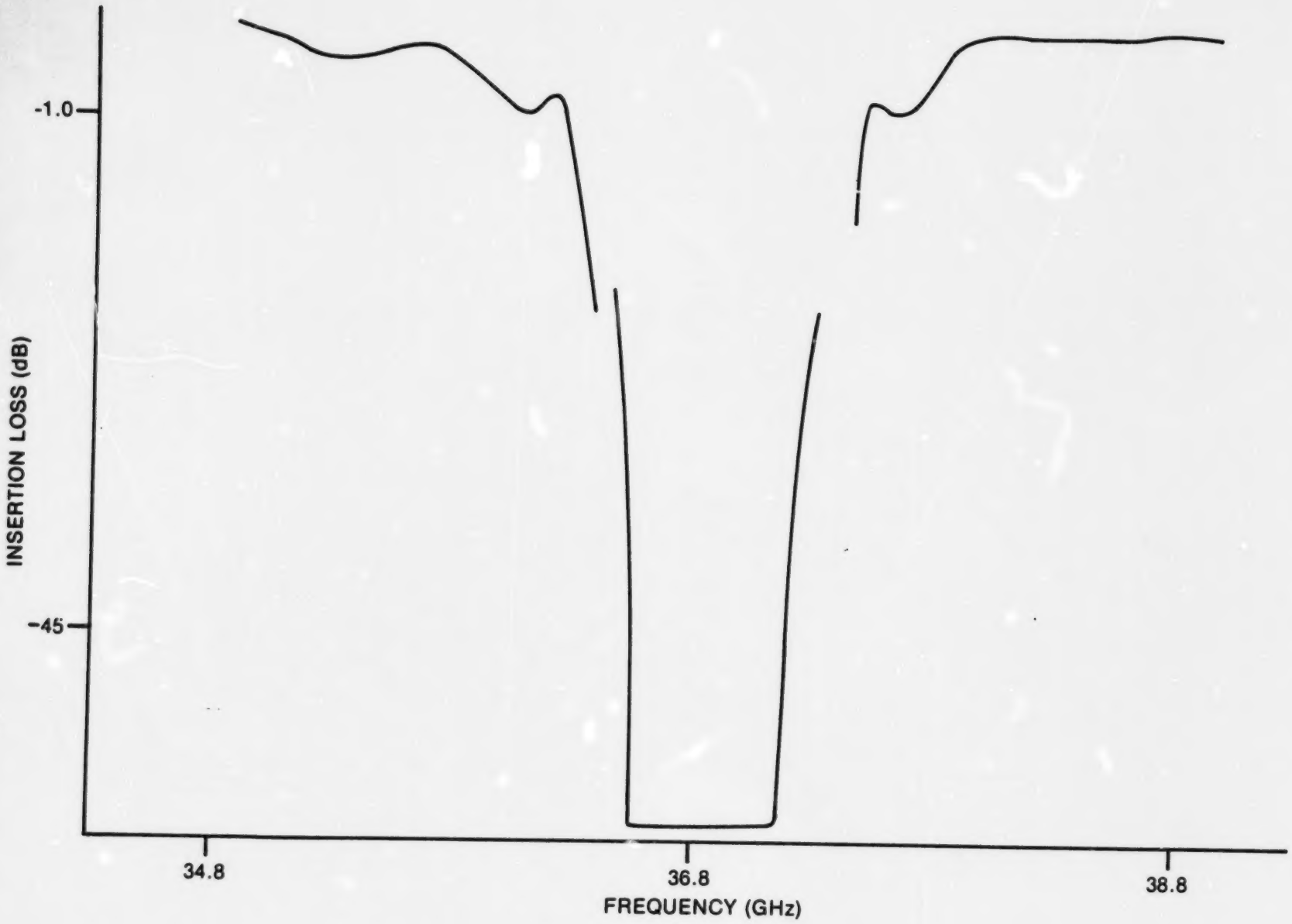


Fig. 16 Band Stop Filter Plot

6.6 Tx Signal Amplification

The Tx frequency (36.840/38.040 GHz) for LES 8/9 is level set via an adjustable attenuator and fed to a Watkins Johnson low noise TWT preamp (TWT data is shown in Table 4). The output of this TWT amp is fed through a TRG series-Y junction isolator, an attenuator, and a 10 dB directional coupler to a Hughes TWT amplifier model 1177H (Fig. 17).

The Hughes TWT output is fed through a broad band isolator and a 20 dB cross guide coupler (which provides forward/reverse power monitor points) to a second switched bandpass filter network as described in Para 6.5. The transmit frequency is switched via a 4 port switch to one of two ports in the antenna feed assembly.

6.7 Antenna and Feed System

The feed assembly consists of an ALPHA TRG orthomode transducer model A881, circular polarizer model A882, tapered mode transition Model A884 and a conical feed horn. The feed assembly is shown on the left hand side of Fig. 18. Transmitting into the side arm of the orthomode transducer launches a right hand circular polarized wave, while transmitting into the through arm launches a left hand circular polarized wave.

The antenna is a 6 foot diameter Cassegrain type, constructed of a plastic material with a metalized surface, and an aluminum core structure. The surface finish tolerance is .006 inches RMS. The antenna, feed horn and subreflector is shown in Fig. 19. Patterns for the antenna are presented in Appendix A. These patterns were measured on the David Florida Laboratory at CRC with the antenna mounted in an anechoic chamber. The antenna system was integrated into a Scientific Atlanta series 3100 pedestal at CRC.

6.8 EHF Receiver Section

The received satellite signal from LES 8 or LES 9 is delivered via the orthomode coupler, from the through arm if the signal is from LES 8 (LHCP) or the side arm if from LES 9 (RHCP). The received signal is then switched through a band pass/band stop filter pair (the filter selection is dependent upon the satellite in use) with provision being made at the first wave guide switch for the injection of a calibration signal. The filtered signal is fed to the RF port of the down converter, which is a mixer-tripler unit similar to that described in the upconverter path. A low noise IF amplifier is coupled with this unit which gives a double side band noise figure of 5.4 dB (Table 5). The local oscillator is selected through a coaxial switching network to match the receiver frequency plan for the satellite being accessed.

The receiver IF (900/840) MHz is switched through a coaxial bandpass filter, amplified and sent to the control console via RG9 coax cable for IF/base band signal processing.

6.9 Translation Circuits

The translation signal path shown in Fig. 11 samples the transmit power through a 20 dB directional coupler and 30 dB attenuator. The sampled

TABLE 4

DATA SHEET FOR LOW-NOISE TWT AMPLIFIER

Tube Type WJ-467-6 Serial No. 1664

Frequency (GHz)	VSWR Maximum		Small Signal Gain (dB)	Noise Figure (dB)	Saturation Power Output (dBm)	
	Input	Output				
26.5	2.5:1	2.5:1	40.8	16.2	13.6	
27.0			41.1	15.8	14.0	
28.0			42.1	15.2	14.7	
29.0			42.9	15.2	14.8	
30.0			43.5	15.2	15.0	
31.0			43.5	15.2	15.1	
32.0			42.2	15.3	14.9	
33.0			42.2	15.3	14.5	
34.0			41.5	15.3	14.5	
35.0			41.1	15.6	14.5	
36.0			41.1	16.3	14.6	
37.0			40.7	16.4	14.5	
38.0			39.7	16.4	14.3	
39.0			39.2	16.8	14.2	
40.0			38.8	17.2	14.0	

Tube Requirements

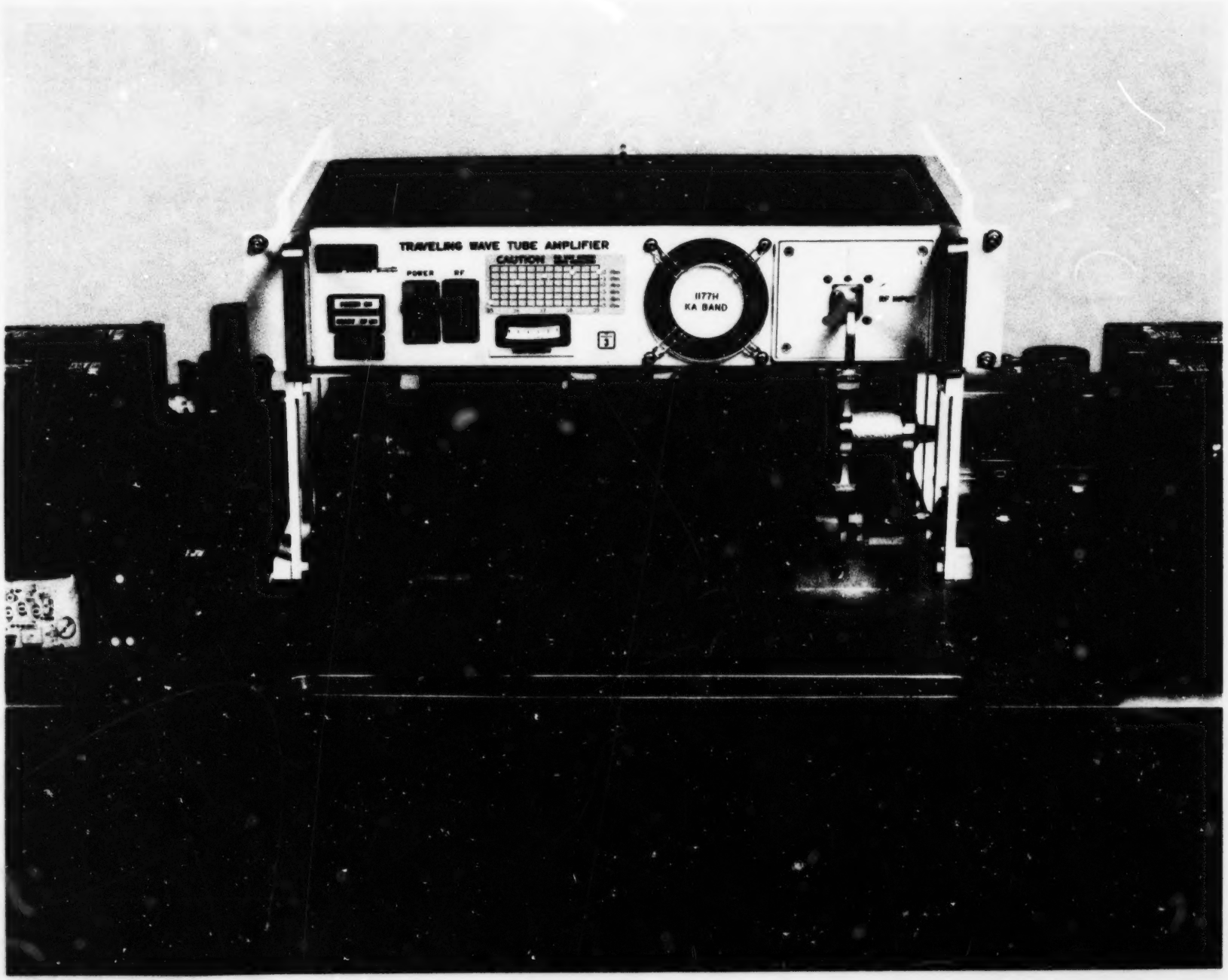
Input Voltage: 105 - 125 V ac
80
Input Current: 230 - 236 mA
Input Power: 20 Watts

Dev. Spec. 27 Mar.

SSG Variation = 5.1 B

Tested by: _____

Date: 9-16-81


TRAVELING WAVE TUBE AMPLIFIER
POWER
RF
1177H
KA BAND

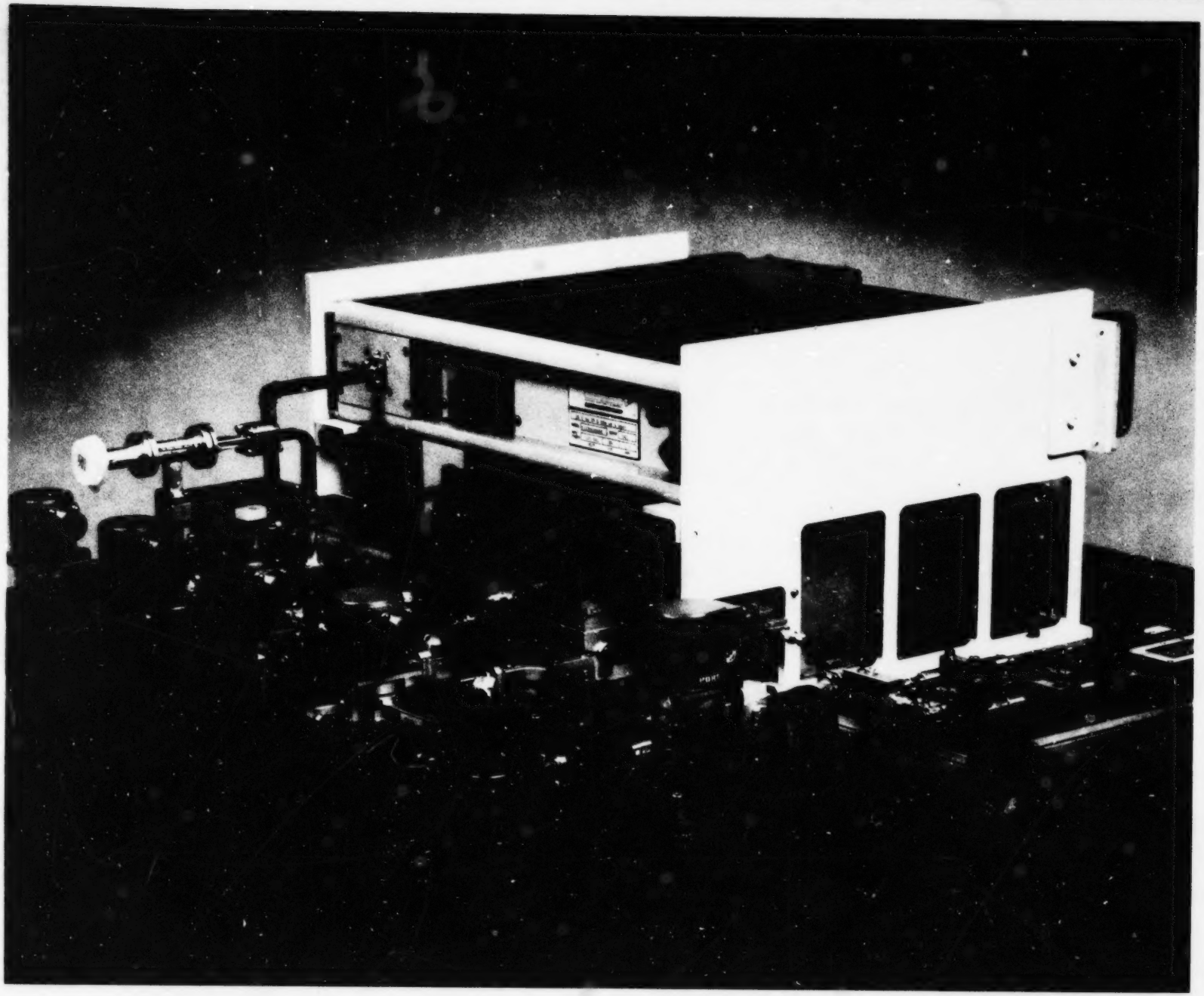


Fig. 18 R.F. Feed Assembly

Fig. 19 Antenna T.R.G. 6' Dia

TABLE 5

Test Data for downconverter SpaceKom Model TF 37-P(S) S/N 0L12

L.O. Input Freq (GHz)	I.F. Output Freq (MHz)	Noise Fig. DSB (dB)	LO Power dBm	LO RF Isolation (dB)	RF IF Gain (dB)	RF input GHz @ -30 dBm
12.380	700	5.4	+17.0	≥ 25.0	28.4	37.840
↓	800	5.3	↓		28.6	37.940
↓	900	5.4	↓		28.8	38.040
↓	1000	5.4	↓		28.1	38.140
12.580	700	5.3	+17.0	≥ 25.0	28.4	37.040
↓	800	5.4	↓		28.3	36.940
↓	900	5.4	↓		28.6	36.840
↓	1000	5.4	↓		28.6	36.740

signal is fed through a 4 port switch to a Spacekom mixer. One of two Frequency West microwave sources (1.200 GHz or 1.2524 GHz) is energized to supply the local oscillator frequency for the translation mixer. This frequency is fed through a power splitter and 10 dB coupler to the LO port of the mixer. The two local oscillator frequencies simulate the two satellite configurations used in the CRC SATCOM terminal (see Table 6).

The IF output from the translation mixer is injected into the receiver signal path through a 20 dB directional coupler. This signal first passes through a 3 port waveguide switch and a level set 30 dB attenuator. This waveguide switch terminates the translate signal path when not in use which provides an additional 50 dB of isolation.

7. EHF TERMINAL SITE

7.1 Construction Details

The antenna pedestal with the integrated RF shelf is enclosed in a ESSCO 12 foot diameter radome. Fig. 20 shows the radome location at the Shirley Bay site before installation. The site selected for the installation of this terminal was on the highest level of the CRC laboratory building at Shirley Bay, Ottawa. Extensive modifications to the building structure were made to ensure a stable platform for the narrow beam antenna.

After support beams were welded into the main structural steel of the building, a concrete pad was poured and the antenna base was mounted and secured into the concrete floor. A raised floor was installed which covers all signal and control cables which enter the radome from the control console. Access to the radome is via an indoor circular stairwell. Provision for installation and removal of test equipment via floor hatches was also included. Heating and cooling of radome is via electric panel units and window type air conditioners mounted in the radome base wall. The completed radome installation is shown in Fig 21.

7.2 Radome Description

The radome was supplied by Electronic Space Systems Corporation (ESSCO) it is a 12 foot diameter radome mounted upon a steel fabricated circular base wall 30 inches high. The base wall is fastened into the concrete floor. The radome specifications are shown in Table 7. Radome electromagnetic performance is shown in Fig. 22.

8. CONTROL CONSOLE

8.1 Equipment Configuration

The control console shown in Fig 23 is located 4 levels below the antenna and radome, on the second floor, a distance of some 200 ft. All control signals and RF signals are routed via cable troughs to and from the console. A video camera in the radome connected to a display in the console room provides visual monitoring of status of the RF shelf and antenna. Provision for audio communications between the console and radome is also

TABLE 6

TRANSLATE FREQUENCY PLAN

LES 8		LES 9	
TO UPLINK	36.7876	TO UPLINK	38.0924
RX FROM DISH	38.0400	RX DISH	36.8400
TRNSL	1.2524	TRNS	1.2524
TO X LINK	36.840	TO X LINK	38.040
RX FROM DISH	38.040	RX DISH	36.840
TRNSL	1.200	TRNS	1.200

Fig. 20 Site under construction

Fig. 21 Radome Installation at C.R.C.

TABLE 7

METAL SPACE FRAME RADOME SALIENT FEATURES

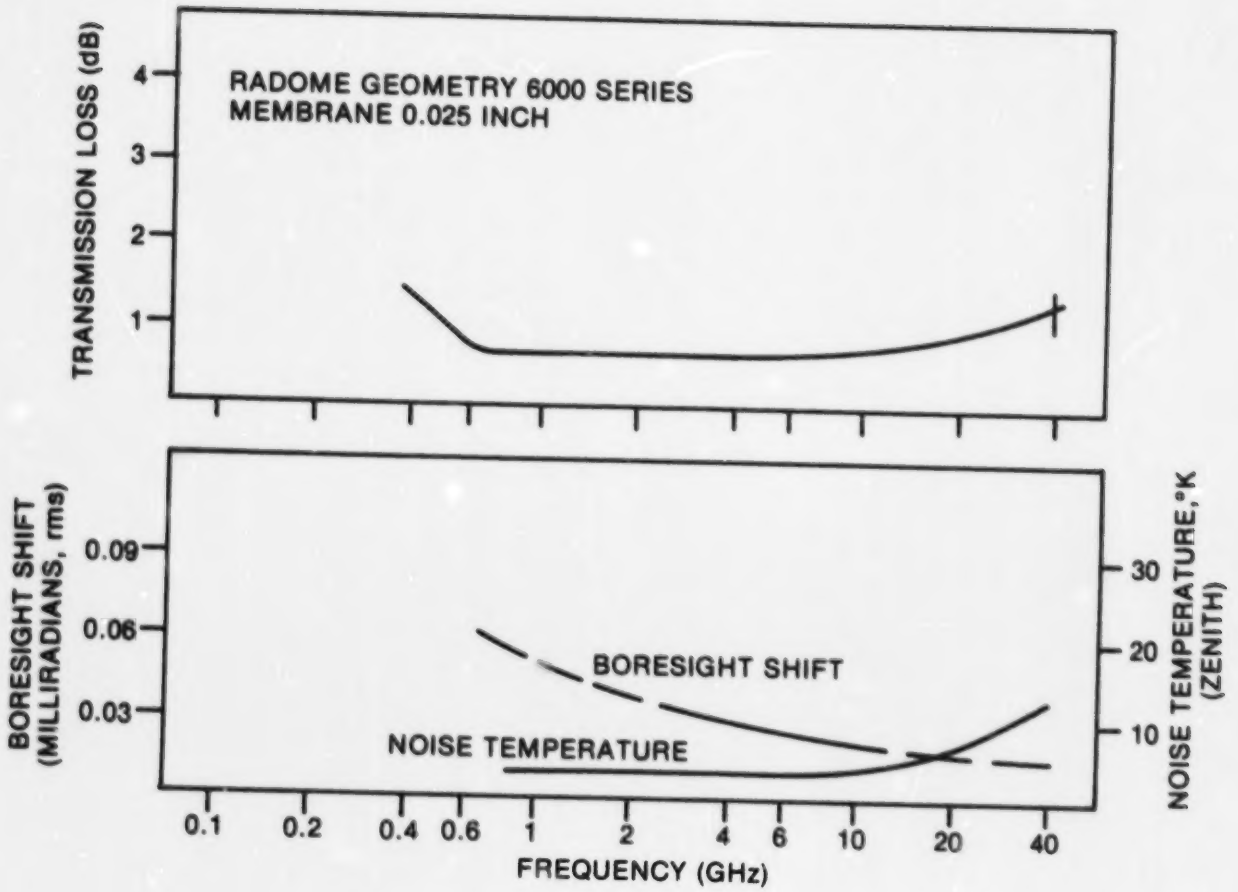
NOMINAL DIAMETER - 18 FEET

ELECTROMAGNETIC

Nominal Performance Values: transmission loss, boresight shift, and noise temperature contribution	See Electromagnetic Performance Graph, Figure 22
Sidelobe Perturbation	1 dB ave. at -25 dB power level with antenna gain >45 dB
Panel Membrane Dielectric Constant	3.0
Panel Membrane Loss Tangent	0.01
Electrical Resistance between Panel Beams	10 milliohms or less

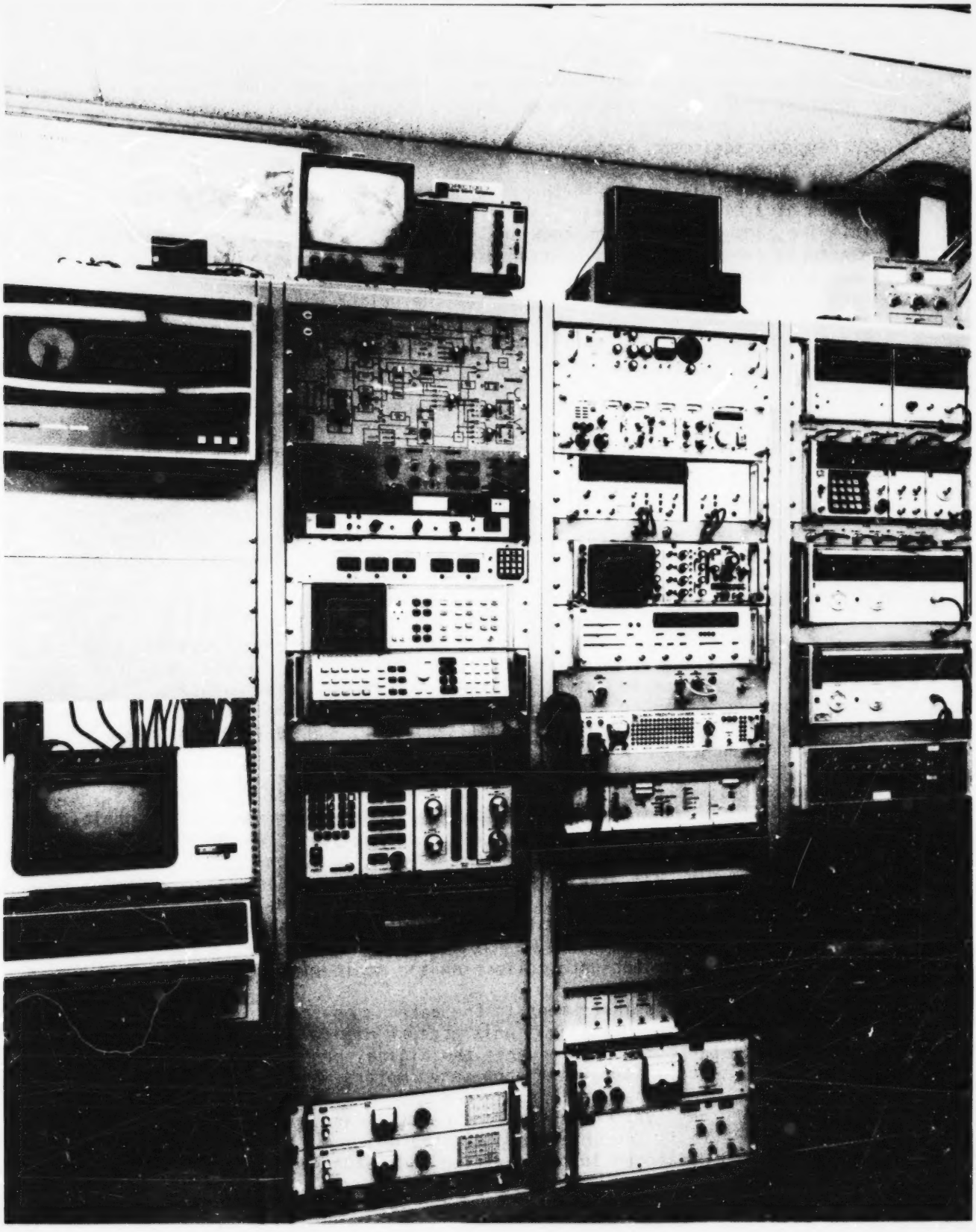
MECHANICAL

Panel Frame Material	6061-T6 Aluminum, or equivalent
Panel Membrane Material	ESSCOLAM 6™
Panel Membrane Surface	TEDLAR, Integrally Bonded
Colour	White
Operational Wind Load	150 mph
Relative Humidity	0 to 100%
Ice or Snow Load	70 psf
Altitude at Site	Unlimited
Outside Height	12 feet 8.2 inches
Inside Height	12 feet 4.3 inches
Outside Diameter	18 feet 0 inches
Inside Diameter	17 feet 4.3 inches
Weight	760 lbs
Number of Panels	170
Packaging and Marking	Commercial Standards
Transportability	Air, Land or Sea Transport
External Bolts	Plated
Internal Bolts	Plated
ESSCO Radome Model	M18-70-6000



METAL SPACE FRAME RADOME 18 FEET DIAMETER

Fig. 22 Radome Electromagnetic Performance Graph



made. The console itself consists of 4 racks of equipment functionally divided into computer and ancillary equipment rack, monitor and control rack, IF/baseband processing and equipment interface rack and frequency synthesizer/signal conversion rack.

8.2 Computer Equipment Rack

The computer is housed in the rack on the extreme left in Fig. 23, and consists of a Digital Equipment LSI 11-23 computer with a winchester disk unit. The computer generates look angles for LES 8 and LES 9 and updates the antenna every 10 seconds by transmitting this information to the Scientific Atlanta Model 3843 antenna controller. The computer also generates a doppler correction number for the uplink and downlink doppler frequency shift and transmits this information to the two Dana frequency synthesizers used as local oscillators in the Tx and Rx frequency conversion chains.

The look angles are generated by a computer program that accepts as input ephemeris data describing the orbit of LES 8 or LES 9 satellites. This data is supplied by Lincoln Laboratories and made available to CRC on a monthly basis.

The computer can also be used to collect data on the actual antenna position, signal strength C/N_0, measured doppler frequency etc. and store this information on disk or magnetic tape for subsequent analysis.

8.3 Monitor and Control Rack

The next rack to the right holds the monitor and antenna control equipment. The telemetry panel (on loan from Lincoln Laboratory) is housed at the top of this rack and gives a visual picture of the satellite configuration as commanded by the Lincoln Laboratory Control Center. The telemetry signal is a 100 BPS, PSK modulated signal and is received on a small helix antenna mounted on top of the main EHF antenna.

Directly below the telemetry panel is the master clock - a Systron Donner Model 8110. This clock is read by the computer and used in the orbit calculations. Below the clock is the power monitor panel, which gives a visual display of the transmit output power, VSWR, all local oscillator power levels and a visual warning signal if any of these parameters exceed their normal working levels. Next in the rack is a HP model #8568A spectrum analyser which can be used for system set-up and trouble shooting, or to monitor various real time signals. This instrument is interfaced via HP-IB to the console computer for data collection and monitoring.

Directly below this instrument is the antenna controller - a Scientific Atlanta Model 3843 (Fig. 23). This unit accepts digital positioning information from the computer, converts the digital number into an analog voltage and transmits it to the antenna servo motors which are located in the base of the antenna pedestal in the radome. The antenna position is read from synchro resolvers housed in the pedestal and fed back to the controller, where it is converted to a digital number to close the control loop. It is also displayed in the position indicator register. The

controller can also give the operator optional manual control of the antenna position via slew command hand wheels.

The controller has an auxillary microprocessor housed internally with a "step track" algorithm programmed into PROMS. When in step track mode it accepts an AGC voltage from a telemetry receiver and maximizes this signal via its steptrack algorithm.

The lowest portion of the monitor and control rack contains the digital interface between the computer and the up/down link synthesizers, plus some of the synthesizers.

8.4 Base Band Processing Rack

The top piece of equipment in the base band processing rack is a WWV or CHU Time Code receiver. Its received time signal is fed to the master clock for accurate time synchronization. The telemetry receiver, a Microdyne model 1100-AR, is mounted directly below the WWV receiver. Its purpose is to monitor the 115 MHz downlink signal before the doppler correction has been applied. By supplying an external phase locked first LO to this receiver, doppler information on the received satellite signal can be measured by PLL signal tracking. The relative signal strength of the received signal is also present as the receiver AGC voltage. This voltage can be fed to the antenna controller for use in the steptrack mode.

Moving down the rack we come to the HP frequency counter model 5345A. The tracking oscillator from the microdyne receiver is fed to channel A of this counter, and a calibrated reference signal of 59.9998 MHz to channel C of the counter. The difference between these signals indicates the downlink doppler frequency. This frequency can be read by the computer and stored on the data disk file.

The next piece of equipment is a bit error analyzer HP model 1645A for link testing, and the generation of modulated or unmodulated beacon signals that are transmitted from the CRC SATCOM terminal to the LES 8 crosslink receiver. Below the 1645A is a digital telephone which provides optional voice communications at a 2.5 KBPS rate. This signal is sampled at a 10 KBPS rate and fed to a DECPSK modem. This modem (mounted directly below the vocoder) is a multirate/multi mode unit developed at CRC, which generates and receives a 70 MHz signal. The modulation mode and rate used for LES 8 is a DECPSK 10 KBPS signal. The rubidium frequency standard for the terminal is contained in the bottom of the rack and generates the (5 & 10) MHz reference signals for the entire system.

8.5 Signal Conversion Rack

The final rack contains the frequency synthesizers and mixers for up/down conversion of the Tx and Rx signals. The synthesizer at the top of the rack is an Ailtech model 360D11, used for uplink conversion to 900 MHz. This synthesizer can be controlled by the computer for use as a frequency hopped local oscillator for the 900 MHz uplink signal. The next lower synthesizer is a HP Model 8660 used as a local oscillator to convert the downlink 900 MHz signal to an IF signal of 115 MHz. This synthesizer can

also be controlled by the computer. The next 2 synthesizers are Fluke Model 6106B's used to supply the microdyne external first local oscillator and the frequency counter reference signal. Below these units is a Rockland model 5600 used to generate the reference signal at 103.333 MHz for phase locking the telemetry receiver. The final two synthesizers are Dana model 7020 and 7010. These are used to up convert the modem 70 MHz Tx signal to the 115 MHz uplink frequency and down convert the 115 MHz received signal to 70 MHz. These synthesizers provide coherent switching under computer control and are used to generate uplink and downlink doppler correction frequencies.

9. POWER MONITOR AND SWITCH CONTROLLER

9.1 Power Monitor System

The power monitor and switch control system for the EHF terminal is shown in Fig 24. A small LSI 11/03 computer with analog to digital converter is mounted on the rear of the RF shelf housed in the antenna radome.

The computer monitors all critical power levels via the A/D interface in conjunction with calibrated RF crystal detectors. The parameters measured are transmit and reflected power, H.P.A. input power and local oscillator powers for the upconverter and downconverter. This digitized power information is transmitted in a serial format via Gandalf LDS 120 modems from the radome to the power monitor display on the control console. At the control console the serial data is multiplexed into the LED display windows to indicate the power levels in dBm.

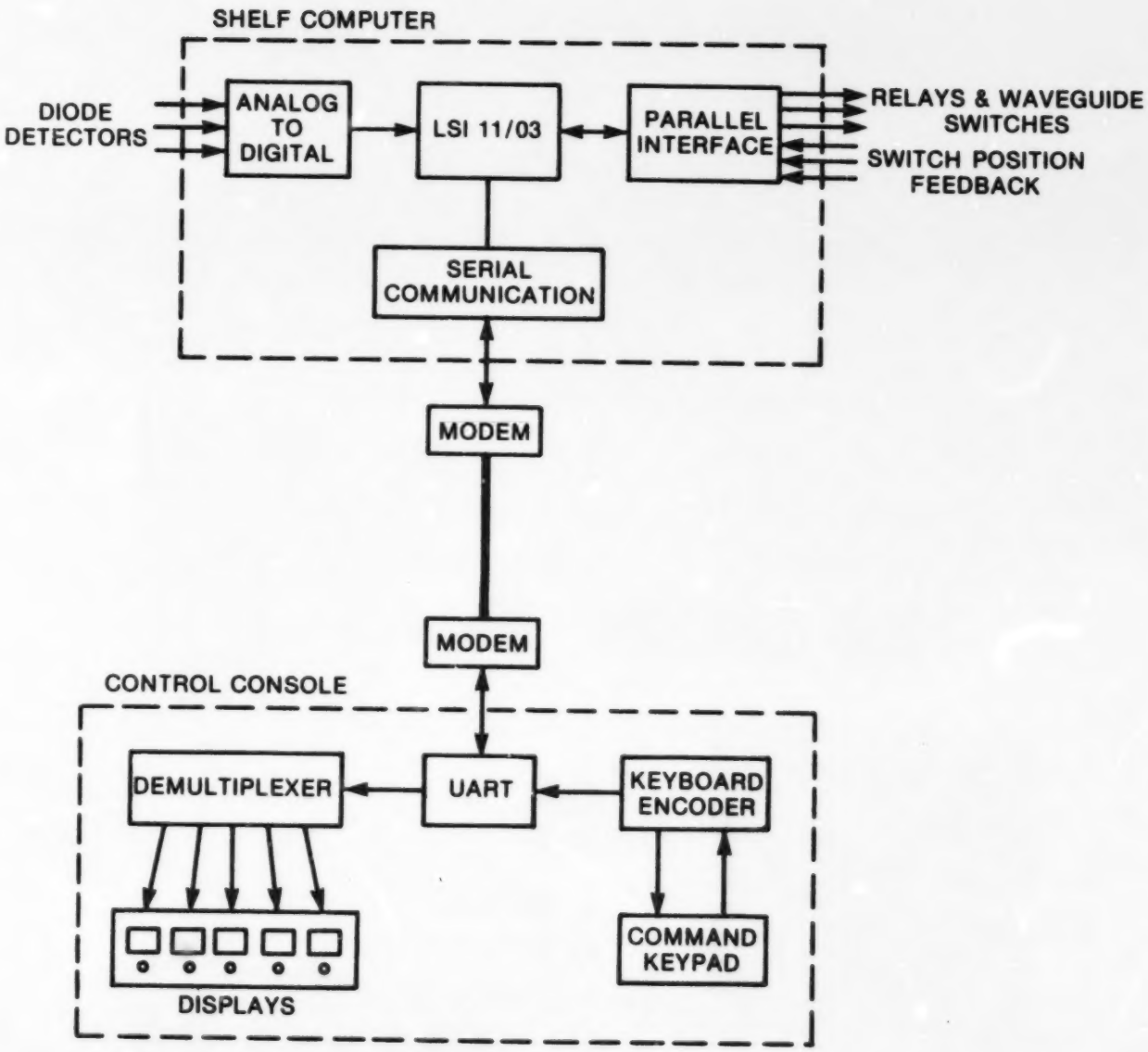
9.2 Switch Control Network

The switch control system allows the operator to remotely select the circuit configuration for LES 8 or LES 9 from the control console. The system consists of a 4 X 4 matrix keypad and keyboard encoder integrated into the power monitor panel. Each key on the keypad uniquely describes a circuit configuration. This digital information is serially transmitted via the LDS modems to the LSI 11/03 computer in the radome and stored in a 16 bit parallel register. The computer sequentially addresses and drives each switch to the position indicated by the register bit pattern. The switch positions are read back into the computer after this operation and checked to confirm that the configuration is correct. A "Switch Set, System Ready" signal is transmitted over the serial link to the monitor panel to indicate via a led display that the terminal configuration is complete. Thus each key describes a unique circuit configuration and turns on or off the transmitter allowing complete operator control of the terminal in the radome from the control console. The power level monitor and keypad are shown in the center of Fig 25.

10. EXPERIMENTAL RESULTS

10.1 SATCOM Experiments

The SATCOM terminal has been used to demonstrate 2.5 KBPS voice



POWER MONITOR AND SWITCH CONTROL SYSTEM

Fig. 24 Power Monitor and Switch Control System

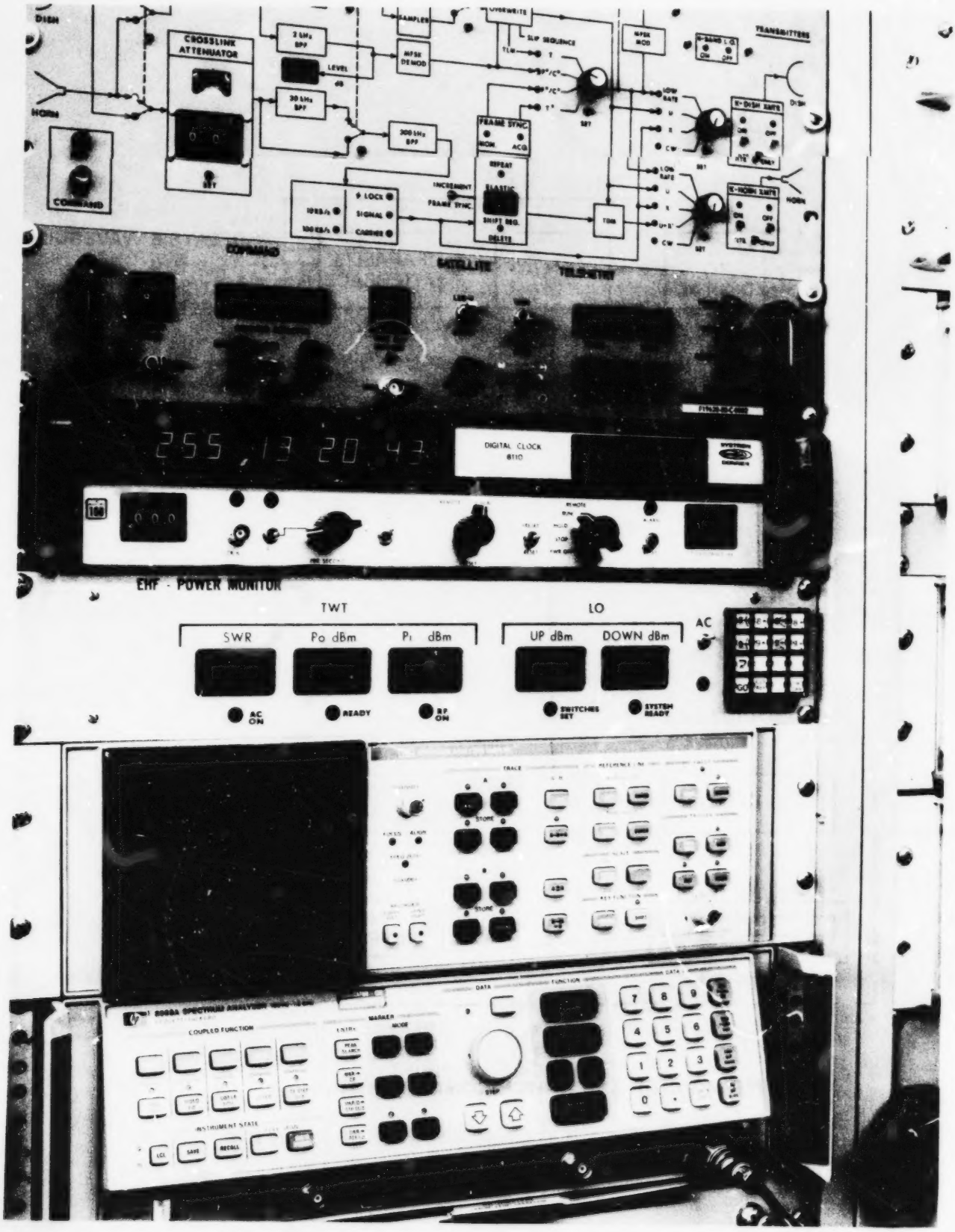


Fig. 25 Power Level Monitor and Keypad

communications between CRC Ottawa and MIT Lincoln Laboratory, Boston, Mass. A program to measure low angle propagation between CRC Ottawa and Alert in the Canadian Arctic has been carried out, and will be reported separately. Other measurement programs have been carried out as described below.

10.2 Satellite Link Attenuation

To record link rain attenuation we used the LES 8 spacecraft CW beacon and the steptrack routine described in section 9.2. The recording device is a HP model 8568A spectrum analyzer. The antenna controller flags the computer when the step track routine has optimized the antenna pointing angles, whereupon the computer reads the peak value of the CW Beacon signal from the HP spectrum analyser. The average value of the system noise floor is recorded next, followed by the antenna azimuth and elevation angles, doppler shift and current time. The computer calculates the C/No and displays this value on a video terminal in a line format with azimuth elevation, doppler frequency and time for operator convenience. These parameters are stored in the disk file and are available for off line data analysis.

From the recorded data a plot of C/N_0 for different atmosphere conditions was made using a HP7221C Plotter. Shown in Fig 26 is the weather effects on C/N_0 for two extreme conditions - a clear day and a rain storm. This plot was made using the spacecraft dish antenna and the EHF CW beacon signal.

10.3 Antenna Pointing Error Plots

An orbital prediction software routine is used at CRC to generate look angles for the LES 8 and LES 9 satellites as viewed from the site at Shirley Bay, Ottawa. This program accepts as input data the orbital elements describing the LES 8/LES 9 orbits that are updated and supplied by MIT Lincoln Laboratory on a monthly basis. The program calculates the azimuth and elevation pointing angles for the correct time as read from a master clock and updates the antenna position every ten seconds.

The second mode of operation for the terminal is a step tracker routine which is incorporated into the Scientific Atlanta Model 3843 antenna controller. The step track routine requires as its input a varying DC voltage proportional to received signal strength which it maximizes by generating a decreasing box scan azimuth and elevation movement until a maximum is reached.

To generate the DC input required for the step track we receive an EHF CW beacon signal from LES 8 or LES 9, down convert this signal to 115 MHz IF frequency and feed it to a Microdyne telemetry receiver. The AGC voltage from this receiver is proportional to the EHF beacon strength which is dependent upon the antenna orientation. When the step track routine has maximized the telemetry AGC voltage we have achieved the optimum azimuth and elevation pointing angles for a given instant in time. The computer now reads the azimuth, elevation and time from the antenna controller and master clock and stores this information on a disk file. It is now possible to compare the data collected via the step track mode of operation with the predicted look angles for the same instant in time and generate an error

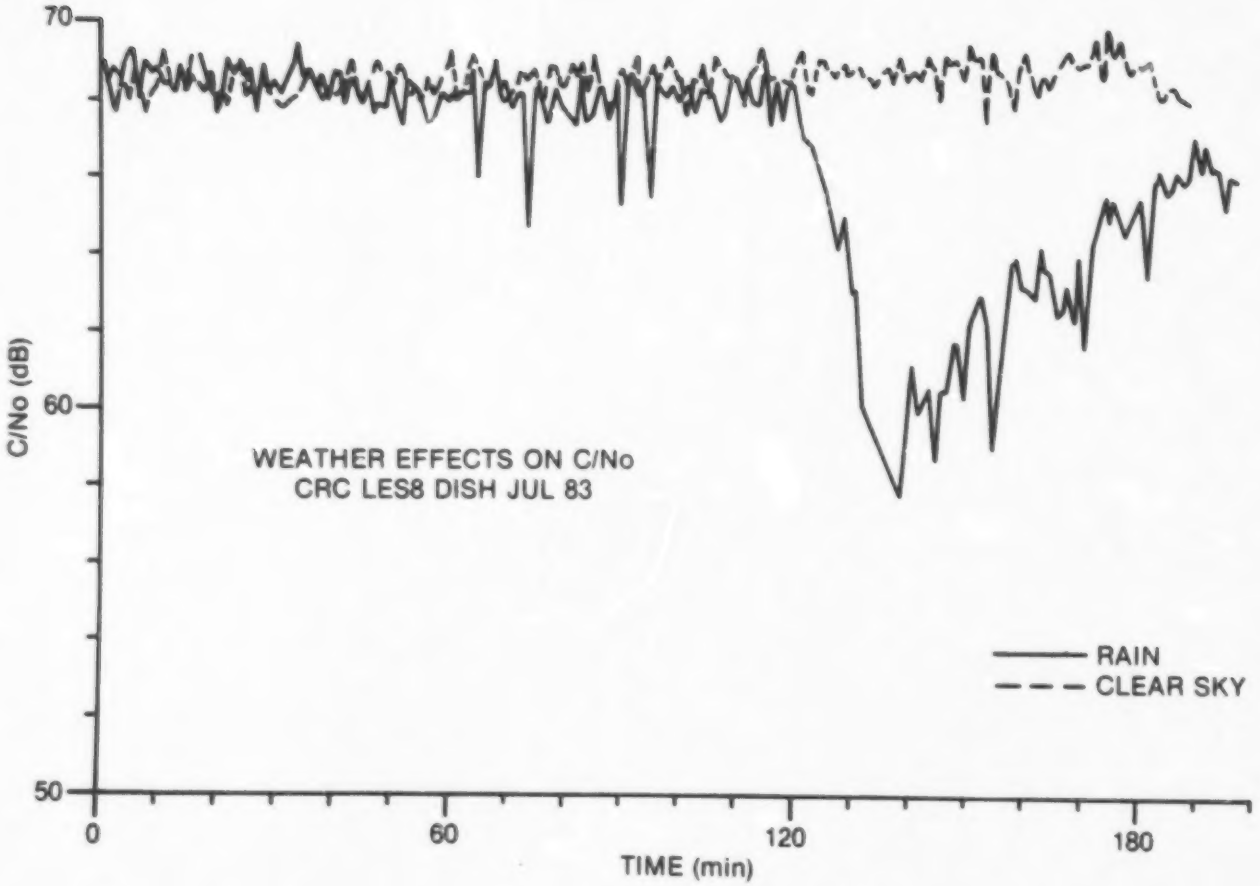


Fig. 26 Signal Strength Recording

plot of calculated vs tracked data over any period of time. Shown in Fig 27 is a plot of the azimuth and elevation angles for the step track mode and the open loop tracking mode taken over a 24 hour period. The tracking mode signal was recorded from LES 8 using the global coverage satellite K horn downlink EHF beacon signal.

10.4 Antenna Pattern Results

Antenna patterns for the 6 foot dia. TRG dish mounted inside the radome were made using the LES 8 spacecraft EHF beacon as the signal source and the CRC satcom terminal for the receiver.

To compensate for satellite motion which would introduce errors in the recorded antenna pattern the orbital prediction software routine was used to locate the satellite at the current time of day. The antenna was then incremented or decremented in 5° steps in the recording plane azimuth or elevation and the signal strength stored by the computer on a disk file. This process was repeated in 1 minute time intervals until a complete antenna pattern was recorded. The antenna pattern for the azimuth cut using the LES 8 CW beacon with the spacecraft dish antenna is shown in Fig 28. The elevation pattern for the same configuration is shown in Fig 29.

The second set of antenna patterns were recorded using the LES 8 CW beacon with the spacecraft horn antenna. The recording technique was identical to the previously described method. For this configuration, the azimuth pattern is shown in Fig. 30 and the elevation pattern in Fig. 31. Using the wide coverage horn antenna serves to eliminate possible satellite dish pointing variations from the antenna pattern data.

11. EXPANSION OF SATCOM TERMINAL

11.1 40/20 GHz Conversion

Plans for the conversion of the SATCOM terminal to an optional 44/20 GHz operating mode are completed and construction is virtually finished. The terminal will be used in conjunction with an EHF satellite repeater placed on a tower in a direct line of sight some 10 miles distant from CRC Ottawa. Experiments using frequency hopping and spread spectrum techniques will be carried out. This new facility will also provide an EHF antenna range for testing experimental feed and antenna systems. These experiments will be the subject of a follow-on report.

11.2 Dual Feed Antenna System

The conversion of the EHF (36/38) GHz Satcom terminal to the (44/20) GHz bands required the construction of a dual frequency circular polarized feed system to mount in the existing 6' dia. antenna. A contract to construct this device was let to Andrew Antenna Co., Whithy, Ontario. The feed system required that a new sub reflector be constructed which replaces the existing unit when in the 44/20 mode. The mechanical configuration of this device matches the existing mounting hardware so as to minimize change over time. The new feed was delivered to CRC in September 1983. The complete system has now been tested with the new 44/20 repeater site some

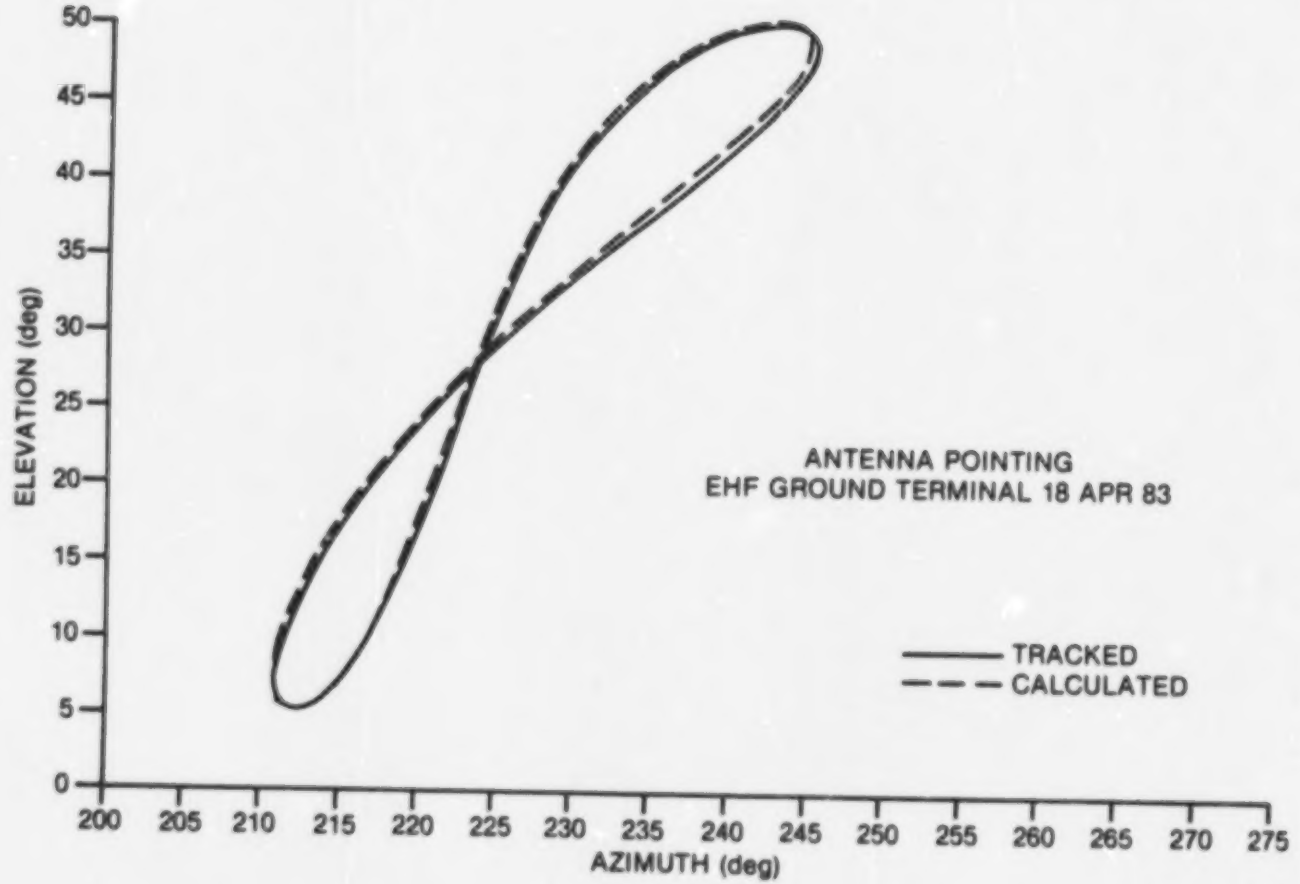


Fig. 27 Antenna Error Pointing Plot

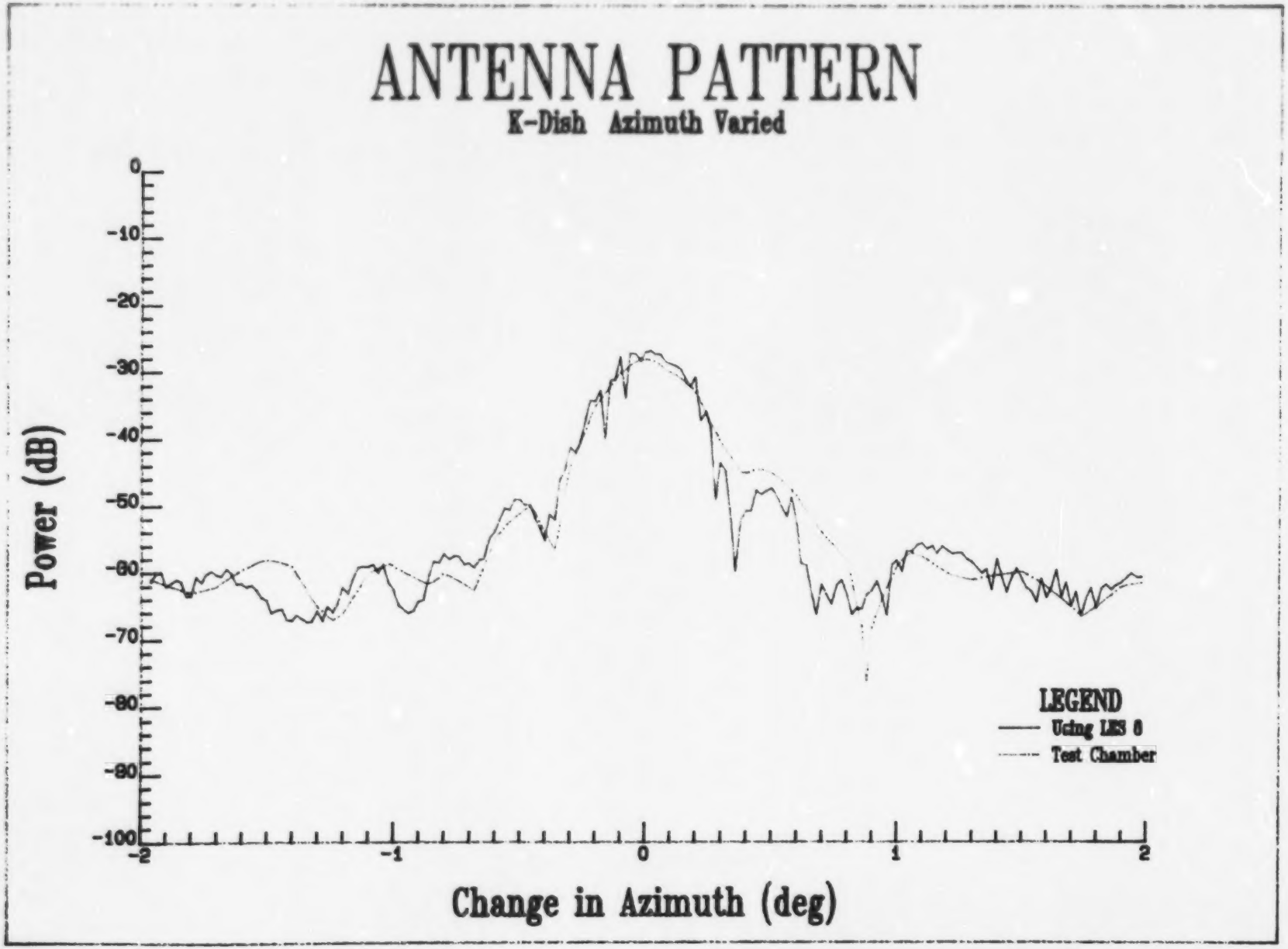


Fig. 28 Antenna Azimuth Pattern - Beacon from LES 8 Dish

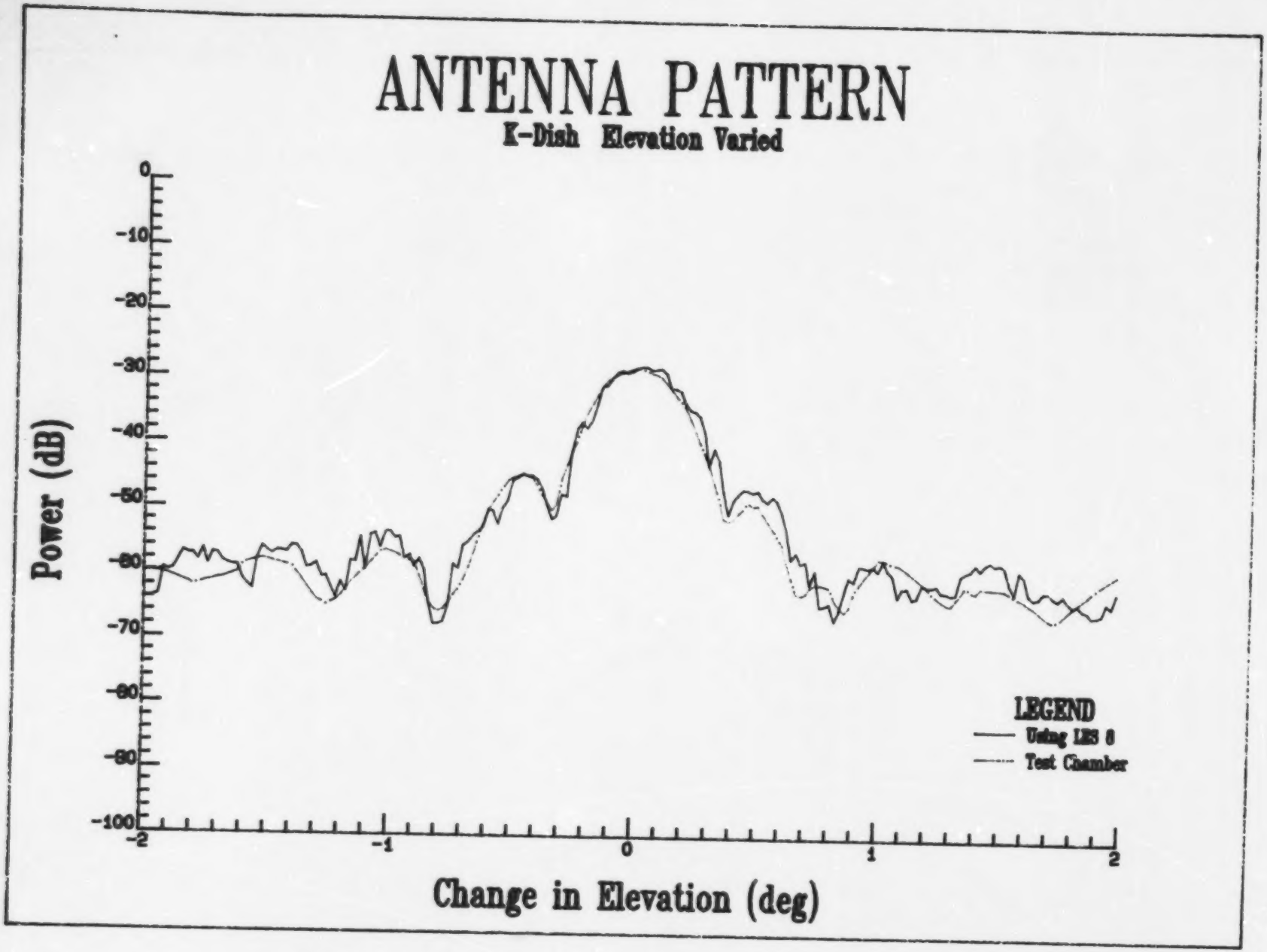


Fig. 29 Antenna Elevation Pattern - Beacon from LES 8 Dish

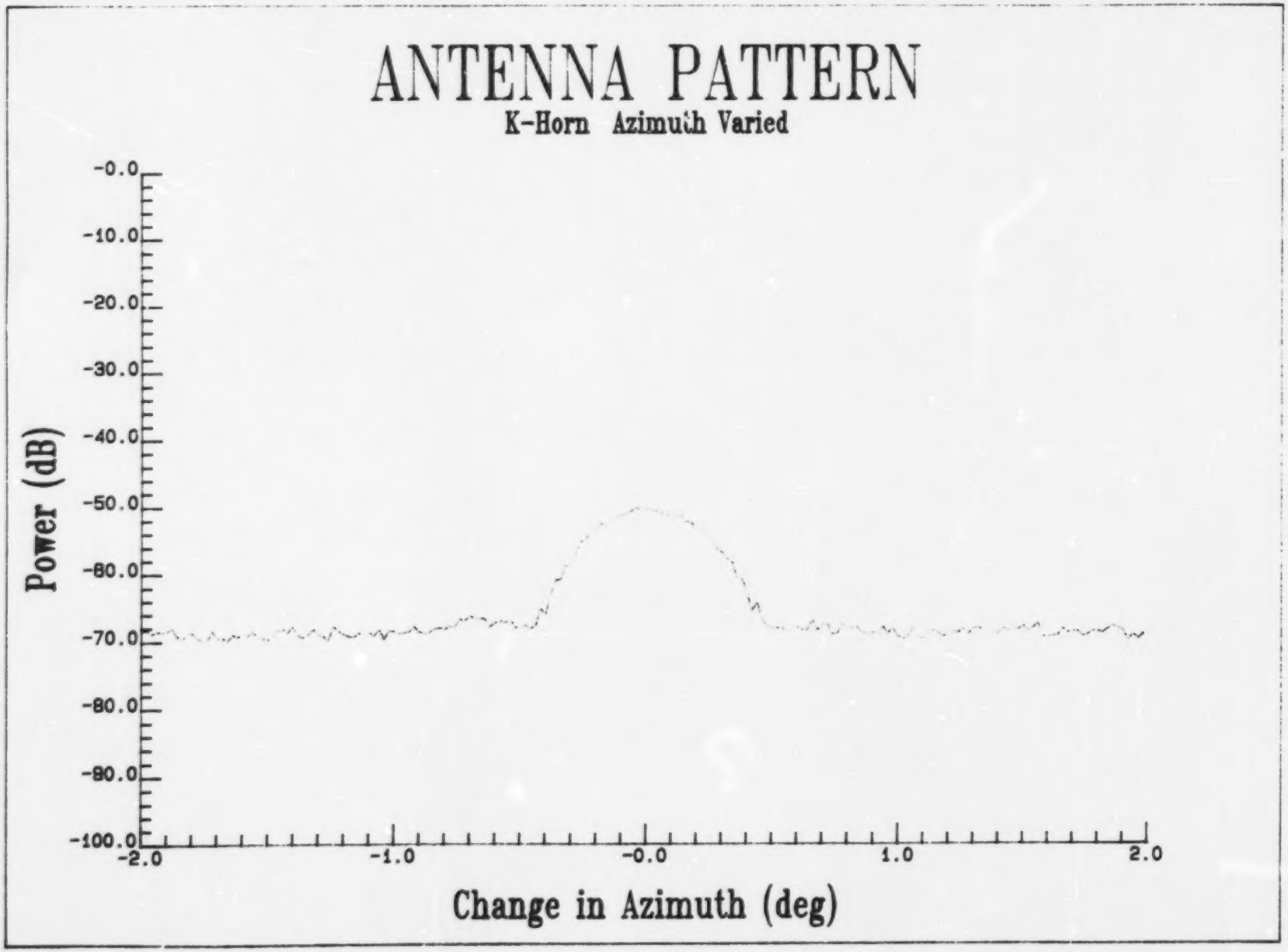


Fig. 30 Antenna Azimuth Pattern - Beacon from LES 8 Horn

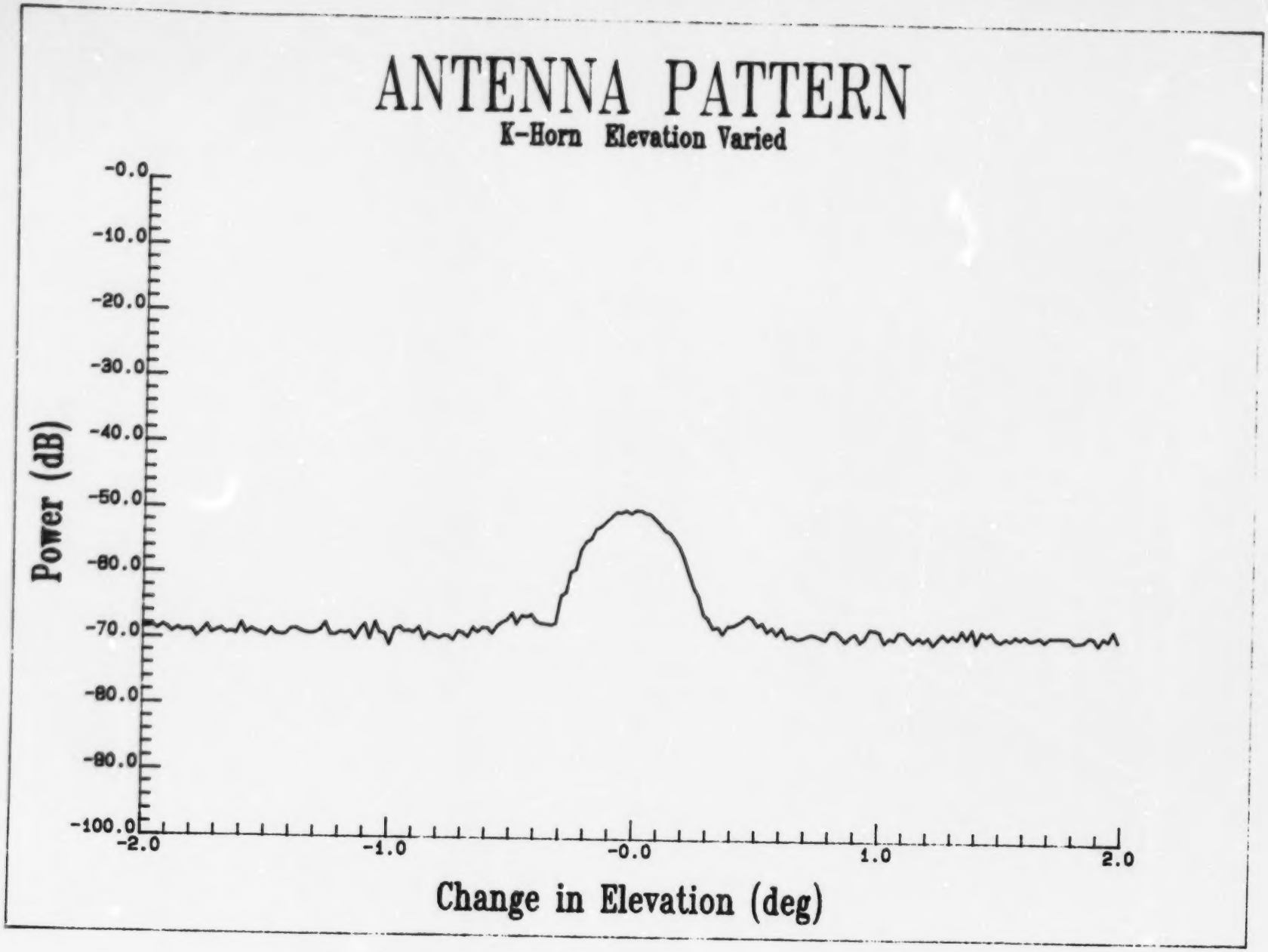


Fig. 31 Antenna Elevation Pattern - Beacon from LES 8 Horn

10 miles from the CRC Satcom terminal. Details will be published in a subsequent report.

11.3 EHF Solid State HPA

A contract to construct a CW solid state amplifier to operate in the Ka band region was let to TRW in May, 1982. An injection locked impatt diode amplifier was developed to meet the specifications listed in table 8. The amplifier was delivered to CRC and acceptance tested in the laboratory environment in May, 1983. The amplifier will be pressed into service when the coolant system is installed in the radome to maintain the operating temperature specification.

This device will replace the Hughes TWT HPA now in service in the Satcom terminal and will be evaluated under actual operating conditions. A report on the evaluation of this amplifier will be published separately.

12. CONCLUSION

12.1

The EHF SATCOM terminal described has been constructed and in use at CRC Ottawa for about 3 years. It has provided a test facility for EHF experiments and will provide a support and base facility for proposed future EHF programs.

13. ACKNOWLEDGEMENTS

A project of this magnitude can only be completed by the contributions of many people. The authors gratefully acknowledge the contributions and help given by Mr. J.D. Lambert, Mr. R. Addison, Mr. D. Sim and the Model Shop and site Plant Engineering support at CRC. Mr. Addison was seconded to the Space Systems Directorate at CRC from the Defence Electronic Directorate, Defence Research Establishment, Ottawa.

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TABLE 8

EHF Solid State HPA Specifications

Minimum Gain		30 dB
Center Frequency		36.790 GHz
1 dB Bandwidth		200 MHZ min.
P/P Gain Variations		±0.5 dB
P/P Power Variation		±0.5 dB
Input Match		1.3:1 VSWR
Output Match		1.5:1 VSWR
AM/PM Conversion		4°/dB
Load Mismatch:	Full Performance	1.3:1 VSWR
	No Oscillations	1.5:1 VSWR
	No Damage	3.0:1 VSWR
Operating Temperature		35°C ±5°C

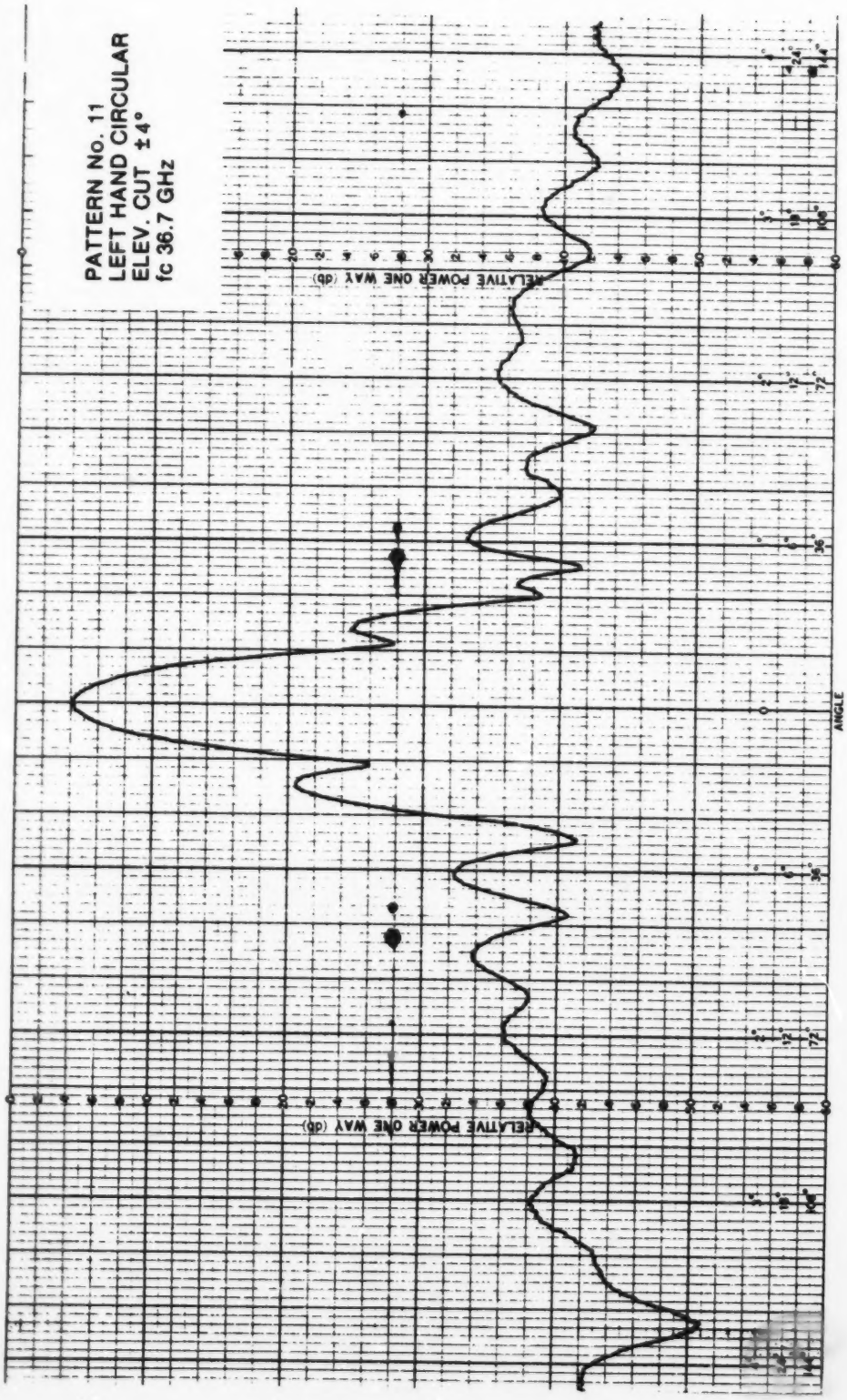
APPENDIX A

ANTENNA PATTERNS

APPENDIX A

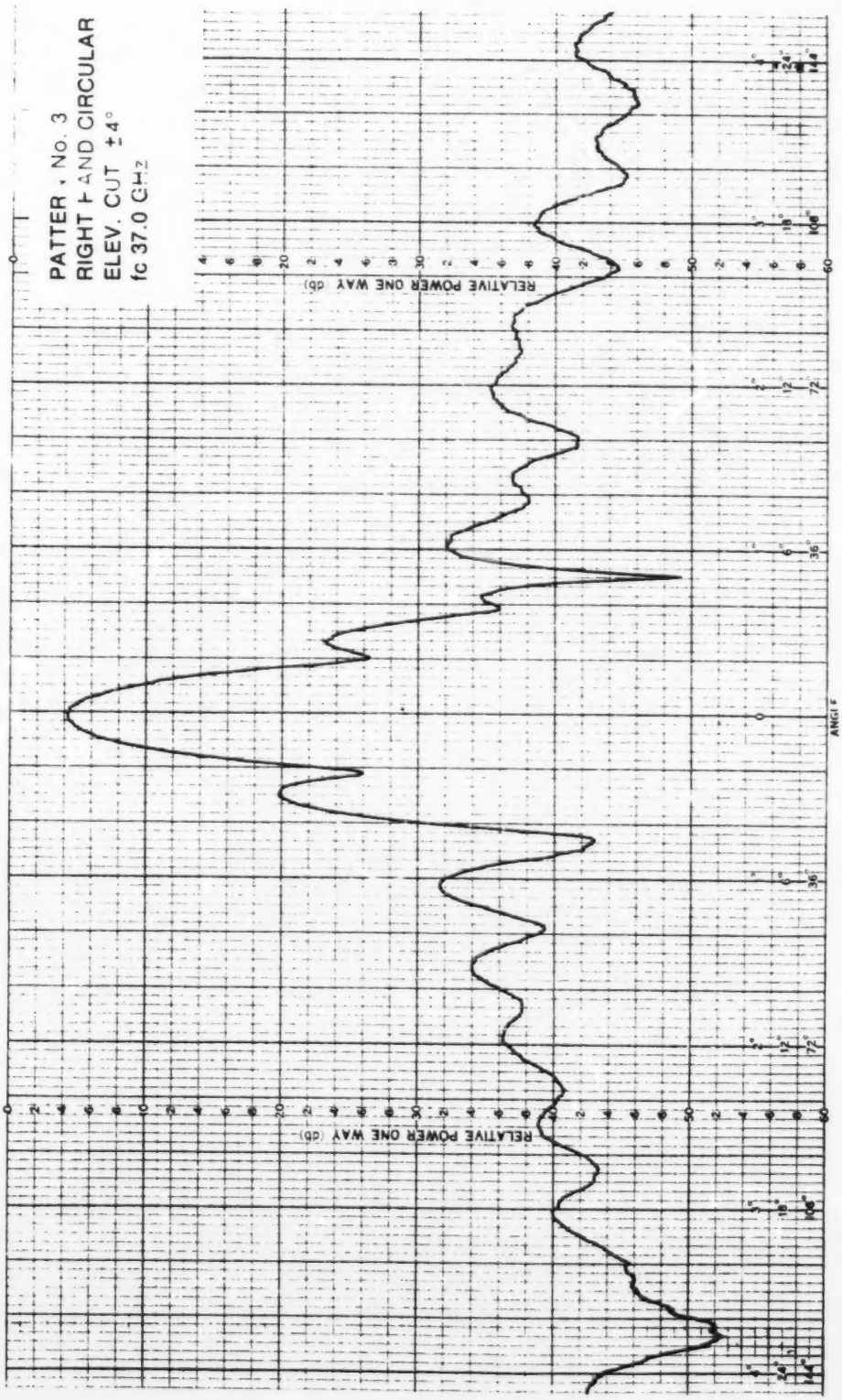
ANTENNA PATTERNS

A-1



TRG ALPHA 6 DIAMETER ANTENNA

A-2



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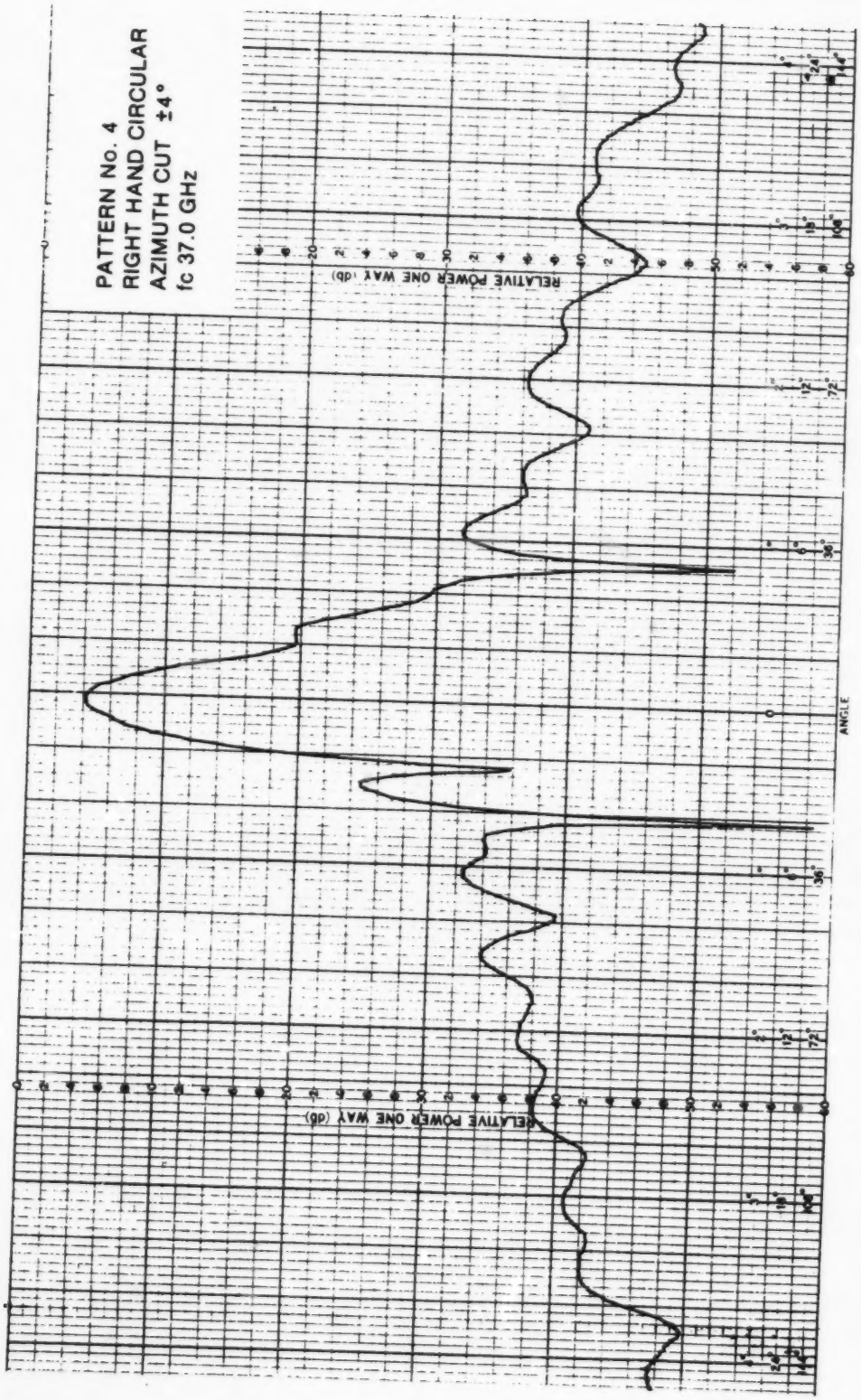

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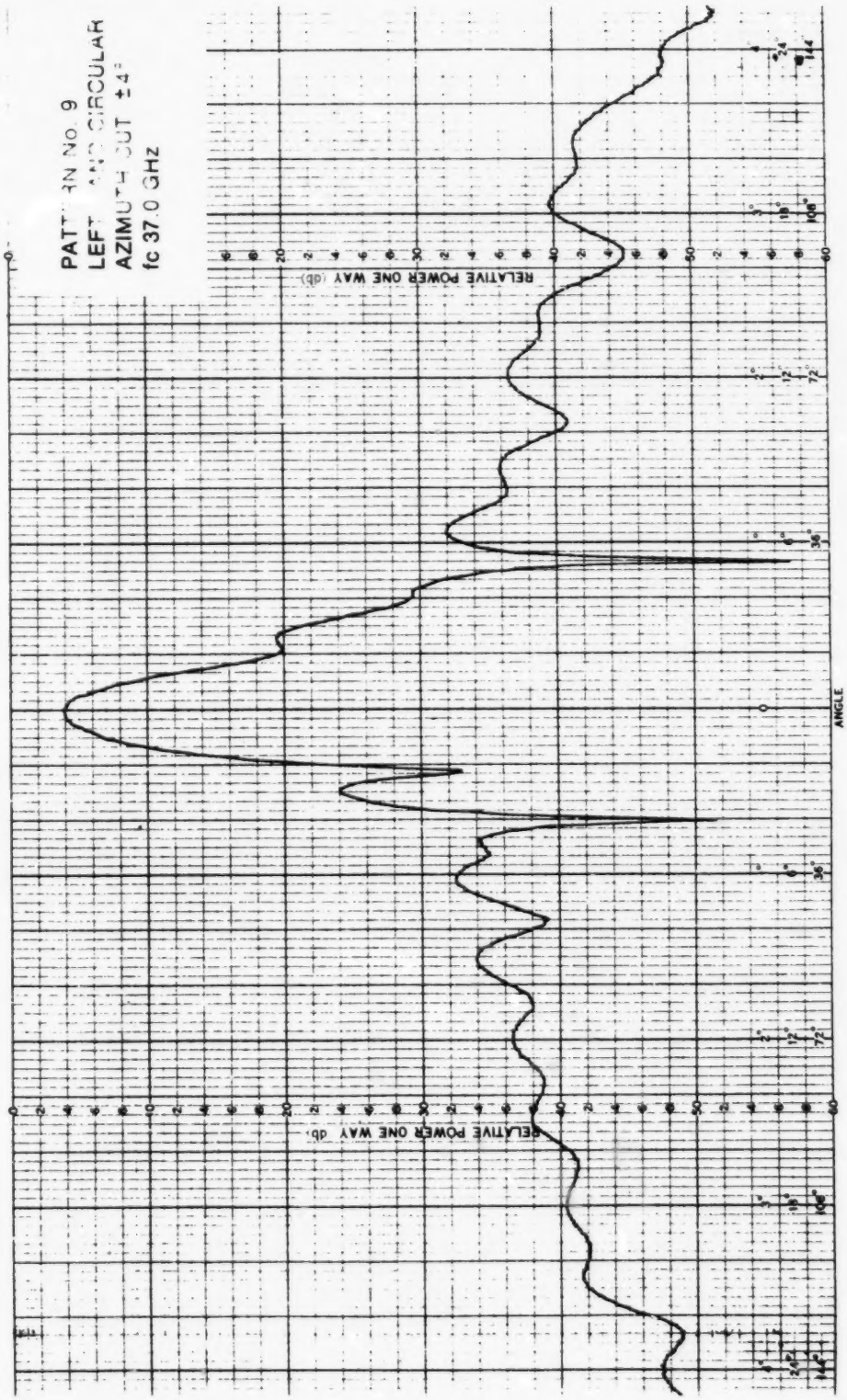

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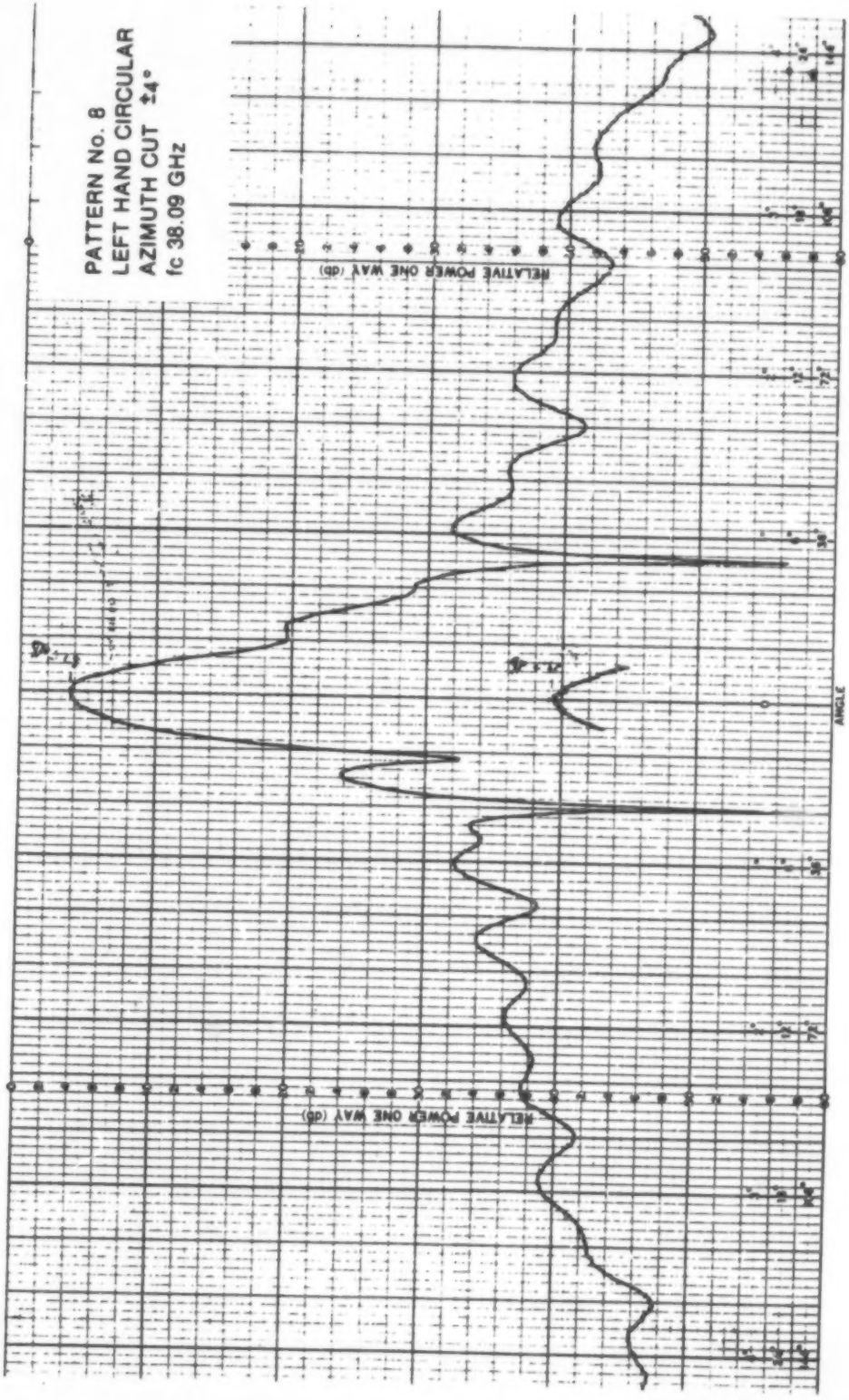

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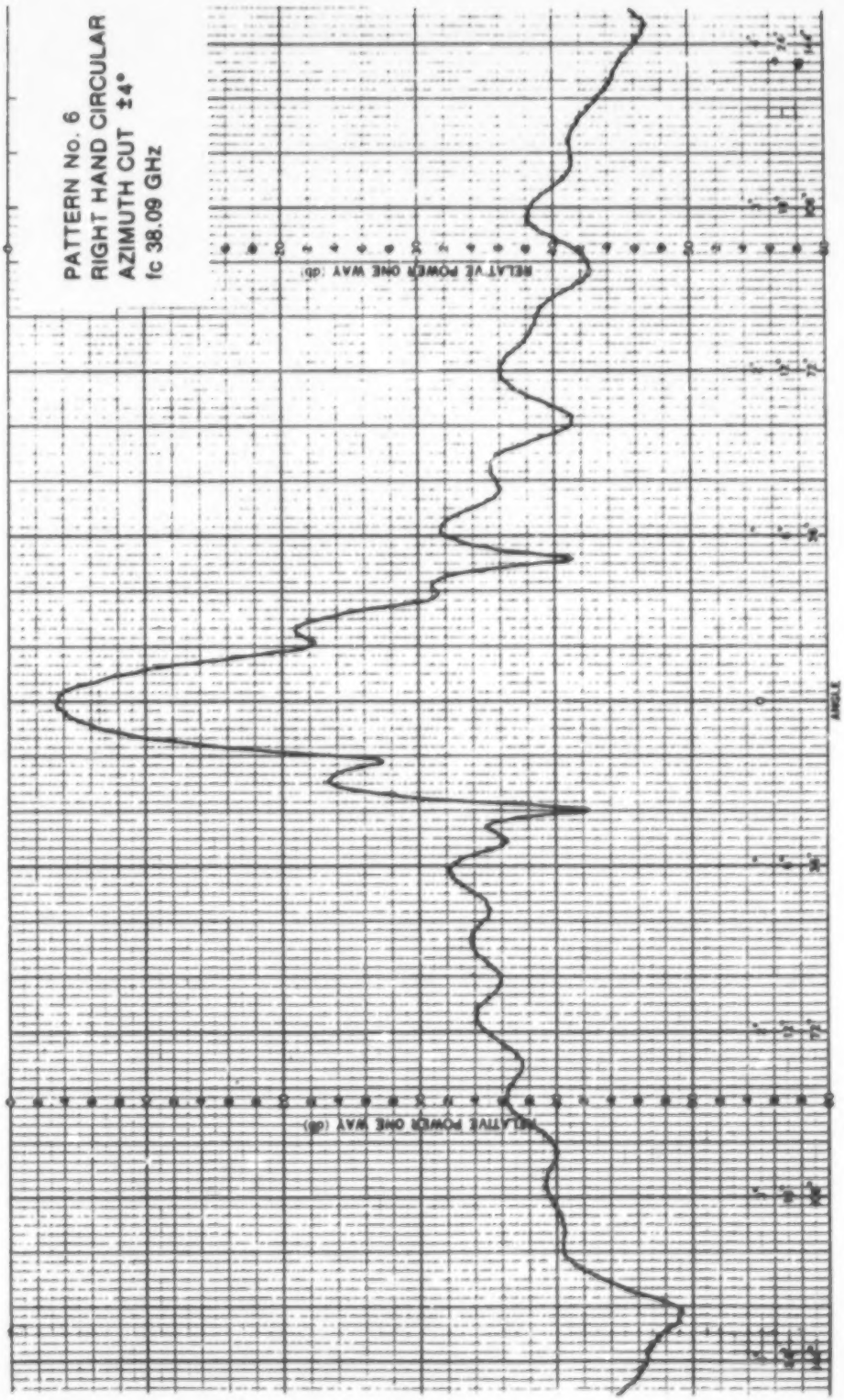
A-6



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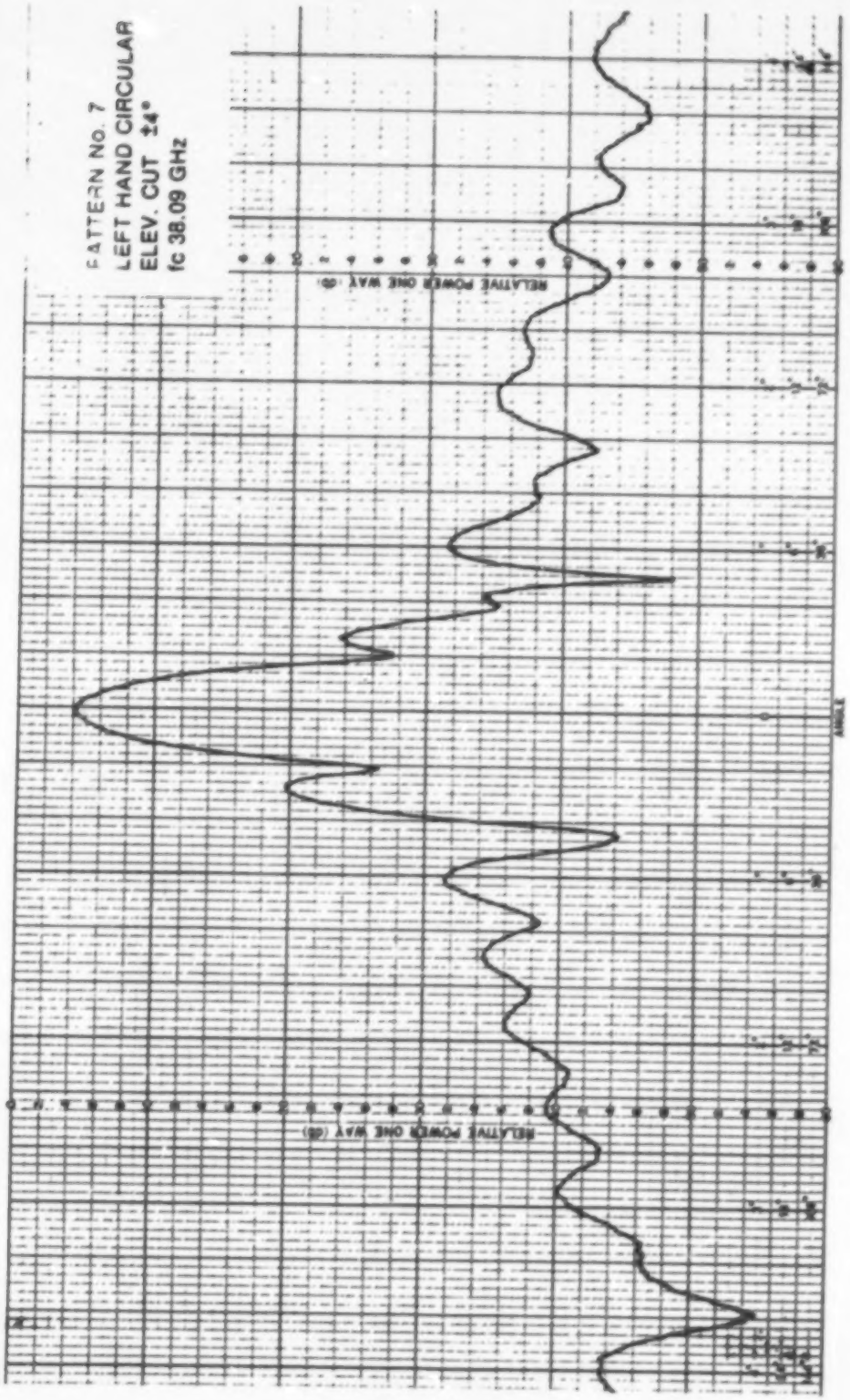

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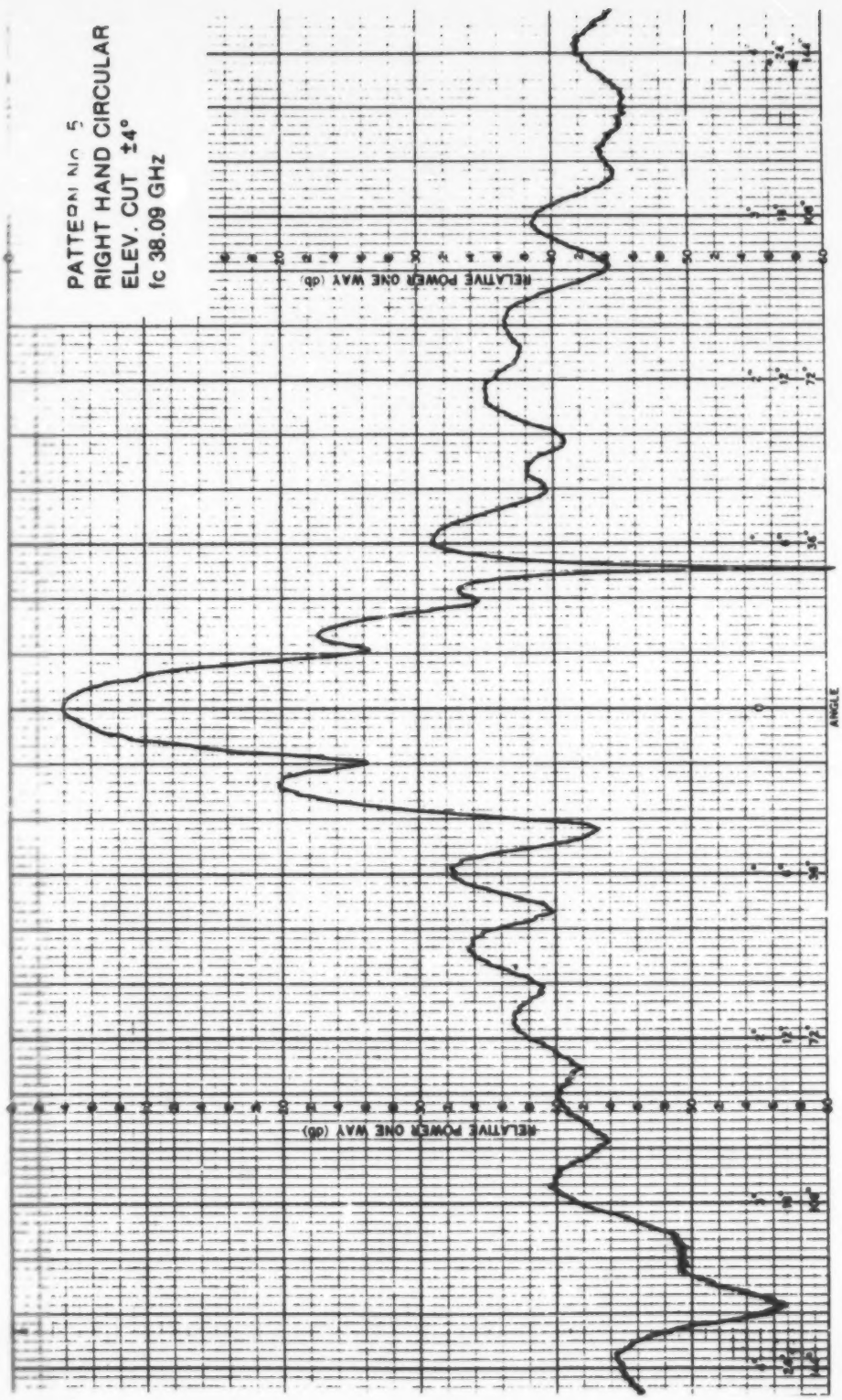

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An E.H.F. SATCOM program was initiated by C.R.C. and D.N.D. in cooperation with Lincoln Laboratory M.I.T. using the satellites LES 8 and LES 9. The early phases of this program, including the design, development and installation of the E.H.F. SATCOM terminal at C.R.C. Ottawa Canada are discussed.

Experiments with the LES 8 satellite are described, the data recorded is presented and future plans for the satcom terminal are outlined.

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